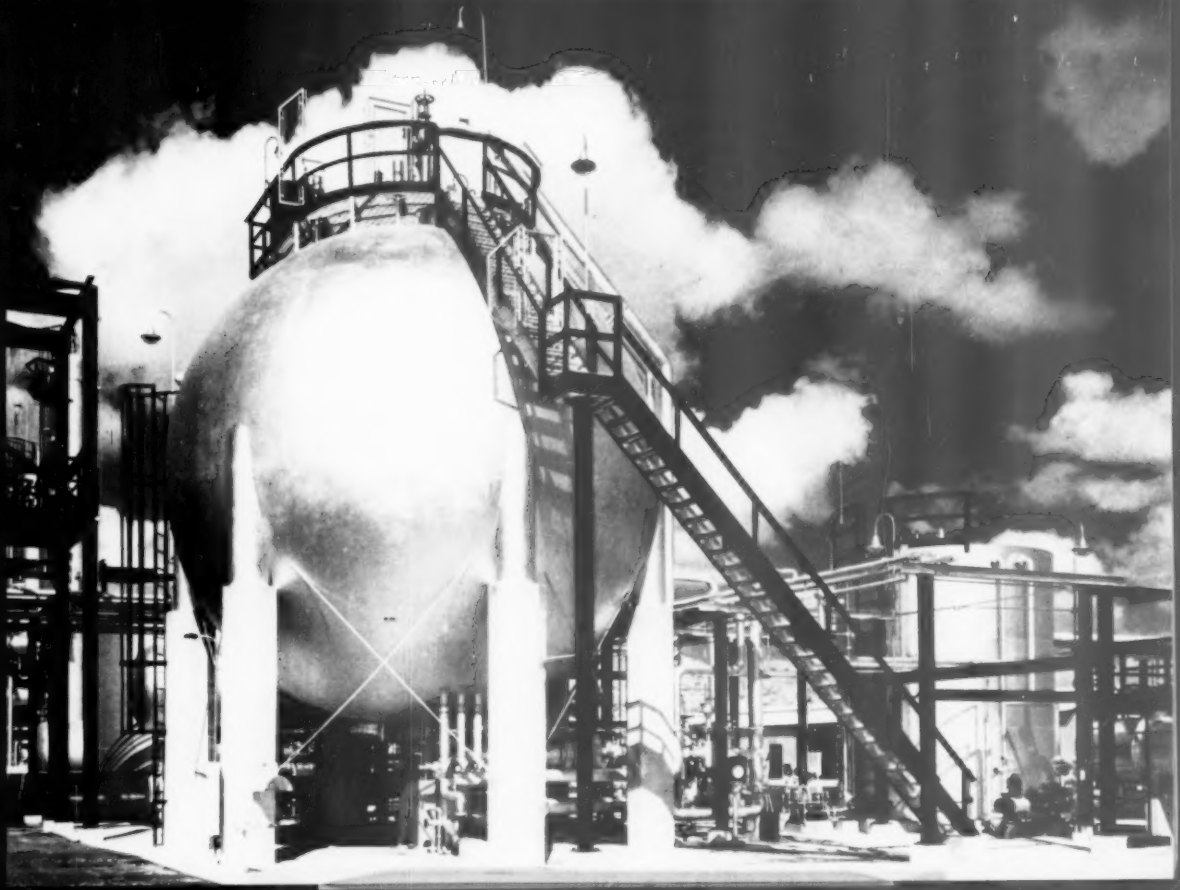
WELDING JOURNAL



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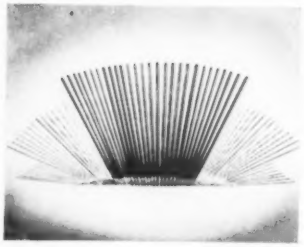

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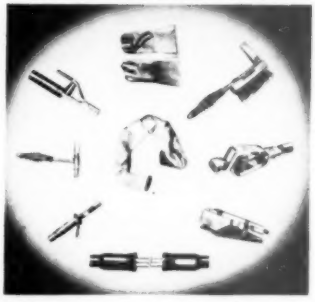

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volume 28 **SEPTEMBER, 1949** *number 9*

CONTENTS

technical papers, items and reports

Shear Strength Consistency of Spot Welds in Alclad, by J. C. Barrett.... 821
Welded Deck Girder Highway Bridge, by Ned L. Ashton..... 832
Double-Headed Fixture Welds Both Ends of Tank at Same Time..... 840
Current Welding Literature..... 840
Resistance Welding Stainless Steel Truck-Trailer Body Components, by Byron Gates..... 841
Cleveland Has a New Building Code, by J. F. Maine..... 846
Economic Electric Arc Welding, by S. Oestreicher..... 848
Joining Wrought Nickel and High-Nickel Alloys, by K. M. Spicer..... 852
Swiss Specification for Gas Welding Rods..... 861
Power Supply for Arc and Resistance Welding..... 863

practical welder and designer

How to Build Cranks and Crankshafts..... 867
Cutting Circles, by J. O. Jordan..... 868
Rowboats Used in Unusual Standpipe Dismantling Job..... 869
Make this Ladder from Pipe, by L. W. Young..... 870
Welding Produces Forming Dies from Scrap Axles..... 871
Welded Repair of a 52-Ton Cast Steel Press Base, by Leslie C. Haynes and J. F. Sloan..... 872
Arc-Welded Beam and Column Framing..... 874
Metallizing of Packing Areas, by J. E. Wakefield..... 875

society and related events

Society News..... 877
INDEX TO ADVERTISERS 878
News of the Industry..... 880
New Literature..... 893
Personnel..... 894
Employment Service Bulletin.. 895
New Products..... 896
List of New Members..... 906
Section Activities..... 907
Abstracts of Current Welding Patents..... 910
Tentative Program Annual Meeting..... 912

welding research supplement

Spot Welding Galvanized Steel, by M. L. Begeman, M. L. Hipple and L. Cullum, Jr..... 385-s
Pearlitic Structure Effect on Brittle Transition Temperature, Discussion by Richard H. Raring..... 395-s
Strain Aging in Welding Structural Steel, by W. H. Bruckner and S. W. Sandberg..... 397-s
Gas Evolution from Weld Metal Deposits, by I. L. Stern, J. Kalinsky and E. A. Fenton..... 405-s
Fatigue Tests of Spot-Welded Steel Sheets, by Dr. Georges Welter..... 414-s
Electrode Coatings Containing Rutile, by R. D. Van Zante, T. R. Graham and R. G. Knickerbocker..... 439-s
Electrical Problems in Argon-Shielded Arc Welding Thick Aluminum, by R. D. Williams, P. L. Mirolo and C. B. Voldrich..... 445-s

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The WELDING JOURNAL

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Shear Strength Consistency of Spot Welds in Alclad 24s-T3

Establishment of the most consistent shear strength levels for spot welds in Alclad 24S-T3 Aluminum Alloy. For each gage combination of this alloy there is a shear strength level at which spot welds made in that combination are the most consistent

by J. C. Barrett

STATEMENT OF THE ORIGINAL PROBLEM

THE spot welding of light alloys for aircraft is controlled by Army-Navy Aeronautical Specification AN-W-30. Table 2 of this specification lists lowest average shear strengths allowed for any particular gage combination. To guarantee that these minimum averages are exceeded in the shop, it is customary to work at strength levels about 15% higher. For gage combinations up to 0.051 in., there is little difficulty in this respect, but trouble is experienced in heavier gage combinations, at least in Alclad 24S-T3. Medium gages, such as 0.064–0.064 in., are difficult to weld on medium machines, such as a 50-kw. electromagnetic discharge Sciaky, without the presence of defective welds. Larger welders must be resorted to until they in turn reach their capacity in stock thickness. A 0.156–0.156-in. gage combination was finally redesigned for riveting when it was found that even the largest machine in the shop was incapable of producing sound welds of the required strength in it.

This insistence on high shear strength values lowers the stock thickness limit which any given machine can weld, because of the high pressures and high heats involved. The Services feel that the specified shear strengths are necessary from the viewpoint of strength consistency. Our immediate concern, then, was to ascertain whether, in heavy-gage Alclad 24S-T3, spot welds of low shear strength are as consistent in strength as spot welds of the present required strength. Such an investigation should establish whether lower strength levels can be used without sacrifice of consistency.

SOLVING OF THE ORIGINAL PROBLEM

The following gage combinations of Alclad 24S-T3 were spot welded for this test:

0.064–0.064 in.
0.081–0.081 in.
0.102–0.102 in.

For each gage combination two strength levels were studied. Attempts were made to strike an average for the low-strength welds about 15% below and for the high-strength welds about 15% above, the AN-W-30 minimum average. These sought after values are as follows:

Gage combination, in.	*AN-W-30* minimum average shear strength, lb.*	*Desired average shear strength, lb.*	
		Low	*High*
0.064–0.064	920	782	1058
0.081–0.081	1400	1190	1610
0.102–0.102	2048	1740	2355

* These values are for a sample size of 20 welds, as our problem concerns itself with certification, which requires 20 shear test specimens.

All stock was degreased for 10 min. in Sprex Aviation cleaner at 180° F., and deoxidized in Oakite 84-A at 180° F. for 8 min. The resultant surface resistance was 15 to 35 microhms.

J. C. Barrett is a Research Metallurgist at the Engineering Laboratories, The Glenn L. Martin Co., Baltimore, Md.

This paper is scheduled for presentation at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

Table 1—Welding Schedules and Consistency Data

(Machine: Taylor-Winfield Hi-Wave, Hydraulic)

Gage combination, in.	Schedule No.	Tip force, lb. Weld	Tip force, lb. Forge	Voltage	Capacitance, mfd.	Time delay, millisec.	Turns ratio	Electrodes Diameter, in.	Electrodes Contour dome radius, in.	Average shear strength, lb., X	Number of welds, n	Standard deviation, lb., σ	Coefficient of variation, %, V
0.064–0.064	1	1000	2700	2650	600	80	450:1	1½	4	802.8	90	31.8	3.96
	2	1300	3500	2650	960	120	450:1	1½	4	1094.9	81	35.7	3.26
0.081–0.081	1	1500	4300	2650	960	130	450:1	1½	5	1024.0	88	51.1	4.99
	2	1700	4900	2700	1080	160	450:1	1¼	5	1214.5	90	52.7	4.34
	3	1900	5500	2700	1800	240	600:1	1¼	5	1641.3	88	86.5	5.27
0.102–0.102	1	2000	6000	2700	1920	240	600:1	1¼	6	1611.4	72	50.3	3.12
	2	2700	8100	2750	2760	240	600:1	1¼	6	2092.6	66	94.1	4.50

For each gage combination and strength level, over 100 welds were made. The pitch and overlap established in AN-W-30, i.e., 1 in. for the two lighter gage combinations and 1½ in. for the 0.102–0.102-in. combination, were used. The length of all panels was 24 in. In order to preserve the overlap, the first two welds in each panel were placed about 4 in. in from each end, and then welding was resumed from end to end. The first three welds in each panel, then, were of a sufficient distance apart to render shunting effects negligible. Also in each panel there were two welds which were shunted in two directions; these were the welds made just in front of the two first welds as welding progressed along the panel. The unshunted welds tend to have higher and the double shunted welds lower strength than the common single shunted weld. In making consistency studies, the strengths of these five welds were discarded, since they were not made under the same conditions as the majority of the welds, which were shunted on one direction.

In Table 1 can be found the welding schedules and consistency data for each gage combination and strength level. One welding machine, Taylor-Winfield Hi-Wave Type HWRD Size 4, hydraulic pressure system, was used for all welding.

It can be seen from Table 1 that tip forces were varied depending on the strength level. We feel this to be a logical approach, particularly since we wish in the end to take advantage of the lower pressure allowable at a lower strength level. In making the schedules of Table 1, we attempted to use tip forces for welding and for forging which were just high enough to avoid internal weld defects. In this way it is believed that the most balanced combination of heat and pressure is realized. Naturally at the higher strength level, higher tip forces were necessary to insure sound welds.

All welds were radiographed and found to be sound and of regular shape. From each set five specimens were sectioned for macrostructure and the remainder were tested in shear. In all cases a period of at least 4 days was allowed to elapse between welding and shear testing, to insure uniform aging of the welds.

In testing dispersion of a group of data, the most useful measures are standard deviation (σ), expressed in definite units (in this case pounds), and the coefficient in variation, V, which is a percentage measure of dispersion. The standard deviation is equal to the square root of the average of the squared deviations, while the coefficient of variation is merely the percentage relation of the standard deviation of a group of data to the average value of the data. The lower these values (σ and V) are, the more consistent are the data. Since we are comparing sets of data with different average values (i.e., high strength against low strength), comparison can be made more readily by use of the coefficient of variation than by use of the standard deviation. We should expect a higher standard deviation at a higher strength level; the coefficient of variation, which is a percentage figure, ignores this, and hence comparison can be readily made.

This statistical method is commonly used, so that further discussion here is not needed. For more complete information and a more detailed explanation, the reader is referred to the *A.S.T.M. Manual on Presentation of Data*, published by the American Society for Testing Materials, 1916 Race St., Philadelphia, Pa.

In comparing the consistency of the shear strength levels (Table 1), it is noted that in two out of three of the gage combinations, the low strength level is more consistent than is the high; only in the 0.064–0.064-in. combination did the high strength level exhibit greater consistency than did the low strength level. This is very interesting, since it contradicts the Services' stand that at low strength levels inconsistency will appear.

The coefficients of variation of the 0.081–0.081-in. combination, both at the low and high strength levels were higher than those found in the 0.064–0.064 in. and 0.102–0.102 in. For this reason an intermediate strength level was established for 0.081–0.081 in.; this appears as the medium strength level in Table 1. Oddly enough, its coefficient is lower than either that of the low strength level or that of the higher strength level.

All welds sectioned for macrostructure were sound, of sufficient penetration, and were well-shaped.

RESTATEMENT OF THE PROBLEM

We have found from the preceding part of this paper that shear strength values of spot welds in heavy-gage Alclad 24S-T3 can be lowered considerably without loss of consistency or a tendency toward duds. The

question then arose, what happens within a wide range of shear strengths, when a balanced pressure-current relationship is maintained? An inkling of what might transpire was afforded us when a third strength level was chosen for the 0.081–0.081-in. gage; it was found that spot welds at the so-called medium strength level were more consistent in strength than those at either a higher or a lower strength. Was there, then, an optimum strength level for each gage combination? If so, a curve of variation against shear strength should appear in the form of a U, with the strength corresponding to the value at the bottom of the U being the optimum strength. If this theory proved valid, and sufficient gage combinations were studied, a curve of optimum strength vs. gage combination could be established. The strengths obtained from this curve should be those which the shop should attempt to meet in production, and any specification minimum values should of necessity be below these optima by a sufficient amount to insure adherence to high consistency.

It was thought worth while to continue the investigation in order to test the validity of the theory presented above. To start with, only one gage combination was chosen, so that further proof of the assumption could be obtained without resorting to a great deal of test work, which would be thrown away if no definite relationship were established. It was decided to try the 0.040–0.040-in. combination first, as it is a commonly used combination and one which many investigators have studied.

FINDING THE OPTIMUM STRENGTH OF SPOT WELDS IN THE 0.040–0.040-IN. COMBINATION

A curve containing five points (i.e., five shear strength levels) should be sufficient to establish a relationship between variation and shear strength. Accordingly, we chose as our lowest value that about 25% below, and as our highest value, that about 25% above, the AN-W-30 minimum average, with the other three levels spaced equally between the high and the low. For the 0.040–0.040-in combination, the five strength levels sought after were (approximately) 350, 400, 450, 500 and 550 lb.

It was further felt that two different types of welding machines should be used, in order to confirm that the optimum strength level is the same regardless of machine.

Table 2—Geometry of Panels

(Dimensions in Inches)

Thickness	*Width*	*Length*	*Overlap*	*Pitch*	*Welds per panel*	*Welds between tip dressings*
0.012	3	24	5/8	5/8	38	10
0.020	3	24	5/8	5/8	38	10
0.040	4	24	3/4	3/4	32	16
0.064	5	24	1	1	24	12
0.081	5	24	1	1	24	12
0.102	6	24	1 1/2	1 1/2	16	16

Accordingly, we chose two medium size machines, a Taylor-Winfield Condenser Discharge, Type HWRD 36-3, and a Sciaky Electromagnetic Discharge, Type PMCO2S-31A, both air actuated, for this work. For each strength level a different pressure cycle was used, i.e., that just high enough to avoid cracking or spitting. This was based on the assumption that the best results would probably be obtained if only enough, and not too much, pressure were used to insure sound welds. The pressure cycles were arrived at as follows: the lowest strength level was set up first, with welding force and forging force just above cracking level; then the highest strength level was set up in like manner; finally the forces for the three intermediate strength levels were spaced equally between those used for the low and those used for the high level. In the case of the Taylor-Winfield machine, it was necessary also to adjust the time delay between weld and forge to the proper setting.

To preserve the overlap without the necessity for tacking at intermediate points, the panels to be spot welded were enclosed in a fixture made of phenol fiber. In this way we were able to proceed in welding from one end to the other of each panel. Between 75 and 100 welds were made for each strength level on each machine. The first weld in each panel was discarded, because, as it was not shunted by a previous weld, it was not made under the same conditions as the other welds. Panel sizes, including pitch and overlap, can be found in Table 2; these dimensions agree with those required by AN-W-30. Also in Table 2 is shown the frequency with which the tips were dressed with emery cloth. About one-third of the spot welds made were radiographed. These were found to be sound.

Prior to welding, the stock was degreased in Sprex Aviation cleaner at 180° F. for 10 min. and deoxidized

Table 3—Welding Schedules and Consistency Data, 0.040–0.040-In. Combination

(Machine: Taylor-Winfield Condenser Discharge, Medium Size, Air Actuated, Type HWRD 36-3)

Schedule No.	*—Tip force, lb.—*						*——Electrodes——*						
	Weld	*Forge*	*Voltage*	*Capacitance, mfd.*	*Time delay millisec.*	*Turns ratio*	*Diameter, in.*	*Contour dome radius, in.*	*Average shear strength, lb., $\bar{X}$*	*Number of welds, n*	*Standard deviation, lb., σ*	*Coefficient of variation, V_c, V*	*Spot diameter in.*
1	850	2130	2000	720	30	300:1	1/8	3	593.1	91	33.32	5.62	0.195
2	800	2000	2150	600	25	300:1	1/8	3	529.4	89	35.03	6.62	0.185
3	800	2000	2000	600	25	300:1	1/8	3	484.5	88	19.07	3.94	0.165
4	750	1864	2150	480	25	300:1	1/8	3	448.7	90	22.42	5.00	0.165
5	750	1864	2050	480	25	300:1	1/4	3	381.9	91	21.51	5.63	0.155

Table 4—Welding Schedules and Consistency Data, 0.040–0.040-In. Combination

(Machine: Sciaky Electromagnetic Discharge, Type PMCO2S-31A)

Schedule No.	Tip force, lb., Weld	Forge	Voltage	Current, amp., secondary	Electrodes, Diameter, in.	Contour dome radius, in.	Intervals, Delay before charge	Recompression time	Average shear strength, lb., $\bar{X}$	Number of welds, n	Standard deviation, lb., σ	Coefficient of variation, %, V	Spot diameter, in.
1	730	1590	Medium	22,015	5/8	3	Long	Long	607.4	79	42.09	6.93	0.210
2	730	1590	Medium	20,825	5/8	3	Long	Long	536.3	90	27.91	5.20	0.195
3	690	1490	Medium	17,225	5/8	3	Long	Long	464.2	91	22.20	4.78	0.175
4	630	1390	Medium	15,470	5/8	3	Long	Long	387.7	91	23.94	6.17	0.160
5	600	1320	Medium	11,900	5/8	3	Long	Long	347.3	90	25.23	7.26	0.140

in Oakite 84-A at 180° F. for 8–10 min. The resultant surface resistance was between 10 and 20 microhms.

The welding schedules used for this work and the consistency data obtained are shown in Tables 3 and 4. From this analysis Fig. 1 was drawn, showing the relationship between coefficient of variation and shear strength for each machine used. The curves of Fig. 1 are definitely U-shaped, and it is seen that the consistency is best at a shear strength level of about 475 lb. This is true for both machines. The curve for the Sciaky machine is more regular, while that for the Taylor-Winfield machine shows a better consistency at the optimum point.

This study of the 0.040–0.040-in. gage combination confirmed what we surmised, that when the proper pressure cycle is used, there is an intermediate strength level which represents the most consistent welding conditions. It is interesting to note that this optimum value (about 475 lb.) falls very close to the minimum average value of AN-W-30 (460 lb.).

From each strength level two spot welds were sectioned for observation of the macrostructure. Tables 3 and 4 list the diameters of these welds, and in Fig. 2 are shown the macrostructures common to each strength level; the welds shown are those made on the Taylor-Winfield machine. Observe that even at the lowest strength level the weld is complete and has good penetration.

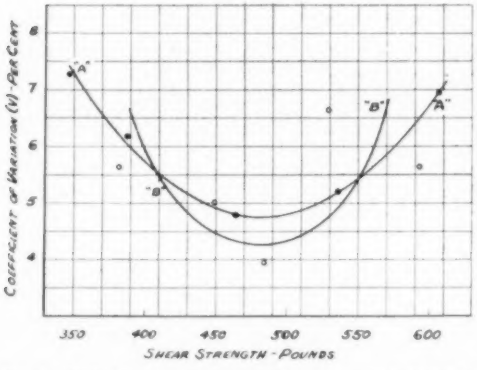

Fig. 1 Variation vs. shear strength of spot welds in 0.040–0.040-in. Alclad 24S-T3

Curve A, Sciaky Electromagnetic Discharge.
Curve B, medium-size Taylor-Winfield Hi-Wave

The success obtained with the 0.040–0.040-in. combination prompted us to continue the investigation with other gage combinations, sufficient in number to construct the curve of optimum strength vs. gage combination.

STUDIES WITH OTHER GAGE COMBINATIONS

The following gage combinations, in inches, were chosen for study: 0.012–0.012, 0.020–0.020, 0.064–0.064, 0.081–0.081 and 0.102–0.102.

In welding these combinations the same procedure was adopted as was observed with the 0.040–0.040 in.:

1. The panels to be welded were placed in a fixture to allow welding from one end to the other

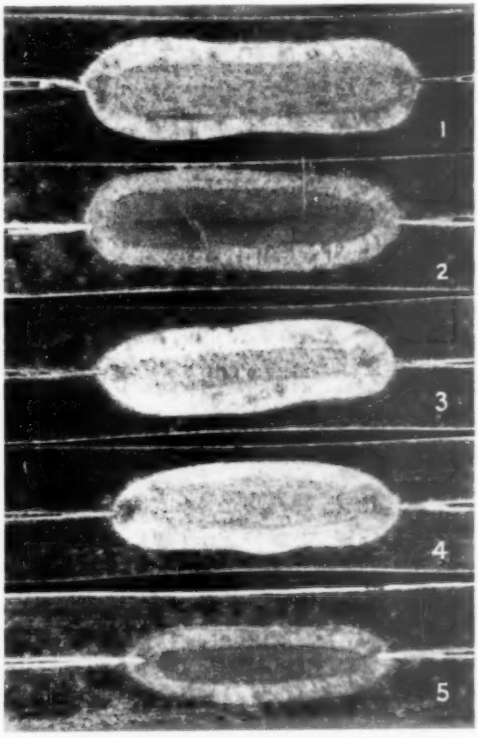

Fig. 2 Macrostructures of spot welds in 0.040–0.040-in. Figures to the right refer to schedule numbers, Table 3

Table 5—Welding Schedules and Consistency Data, 0.012–0.012-In. Combination

(Machine: Taylor-Winfield a.-c., Type EN24-10)

Schedule No.	Tip force, lb.	Tap	% Heat	Pressure system	Weld time cycles	Electrodes: Diameter, in.	Electrodes: Contour dome radius, in.	Average shear strength, lb., $\bar{X}$	Number of welds, n	Standard deviation, lb., σ	Coefficient of variation, %, V
1	300	L-6	100	Single	3	5/8	21/2	147.8	59	14.46	9.78
2	290	L-5	100	Single	3	5/8	21/2	131.1	66	11.77	8.98
3	275	L-4	100	Single	3	5/8	21/2	125.5	72	13.09	10.43
4	260	L-3	100	Single	3	5/8	21/2	112.6	72	11.46	10.16
5	250	L-1	100	Single	3	5/8	21/2	95.7	72	3.71	3.88

and the first weld in each panel was discarded. Panel sizes, pitch, overlap and frequency of tip dressing are shown in Table 2.

2. At least five strength levels, with at least 65 welds at each level, were selected for each combination. In general the AN-W-30 minimum average was chosen as the approximate middle of the range, and strengths ranged from about 25% below to about 25% above this value.
3. The tip forces were varied according to the strength level; the lower the weld strength, the lower the tip force.
4. About one-third of all welds were radiographed. No schedule was adopted that was not productive of sound welds.
5. Two welds from each set (i.e., each strength level) were sectioned for macrostructure, while the remainder were tested in shear.
6. In so far as was possible, all welds in one gage combination were made during one day, to insure consistency of welding machine operation. This is important, as the machines are used commonly for production.
7. All material for welding was degreased in Sprex Aviation cleaner at 180° F. for 10 min. The heavier gages (0.064–0.102 in.) were deoxidized in the regular production tank of Oakite 84-A at 180° F.; surface resistances were maintained between 10 and 20 microhms. The 0.012- and 0.020-in. thick panels were deoxidized in Clepo 180-S, a room temperature deoxidizer. By this method surface resistances between 8 and 12 microhms were realized; with thin gages low resistances such as these are necessary for best performance.
8. All welds were allowed to age 4 days between welding and testing.

Welding schedules for these combinations can be found in tables 5–8. These tables are arranged according to the welding machine used. It is seen that some combinations were welded on more than one machine; this was done in an attempt to find if the optimum were the same regardless of machine.

0.012–0.012-In. Combination

For the 0.012-0.012 in. combination, a Taylor-Winfield a.-c. machine, Type EN24-10, 100 kva., was first selected, with schedules and test results as shown in Table 5. No curve could be drawn from these data, as the lowest strength level, 95 lb., was the only level which showed a variation within a reasonable range. The welds at the higher strength levels seemed to have too great penetration, and difficulty was experienced with tip pickup.

It was concluded that a small Taylor-Winfield motor driven condenser discharge machine, Type HWRD Style 4, would be more adaptable to the welding of this combination. This machine was accordingly used, with the schedules and resultant shear data shown in Table 6. The corresponding curve, Fig. 3, shows an optimum shear level of about 87 lb. This is surprisingly low, when one considers that the AN-W-30 minimum average for this gage combination is 100 lb. The value of 87 lb. optimum corroborates in part the data obtained on the a.-c. machine, and had we realized the low level of this optimum, we could have studied lower strength levels on the a.-c. machine.

In observing the curve of Fig. 3, one notes that the lowest strength level (71.9 lb.) is very inconsistent. This is because of the appearance at this schedule of some very small welds, which in some cases are almost duds. It may be that the optimum strength according to the curve is a little too close to this condition for

Table 6—Welding Schedules and Consistency Data, 0.012–0.012-In. Combination

(Machine: Taylor-Winfield Condenser Discharge, Small Size, Motor Driven, Type HWRD Style 4)

Schedule No.	Tip force, lb.	Voltage	Capacitance, mfd.	Turns ratio	Electrodes: Diameter, in.	Electrodes: Contour dome radius, in.	Number of welds, n	Average shear strength, lb., $\bar{X}$	Standard deviation, lb., σ	Coefficient of variation, %, V	Spot diameter, in.
1	375	2750	120	150:1	5/8	21/2	70	100.2	5.72	5.70	0.105
2	350	2600	120	150:1	5/8	21/2	65	104.9	9.11	8.68	0.105
3	300	2450	120	150:1	5/8	21/2	72	96.2	5.62	5.84	0.085
4	275	2300	120	150:1	5/8	21/2	69	82.5	2.66	3.22	0.080
5	275	2000	120	150:1	5/8	21/2	72	71.9	12.90	17.90	0.070

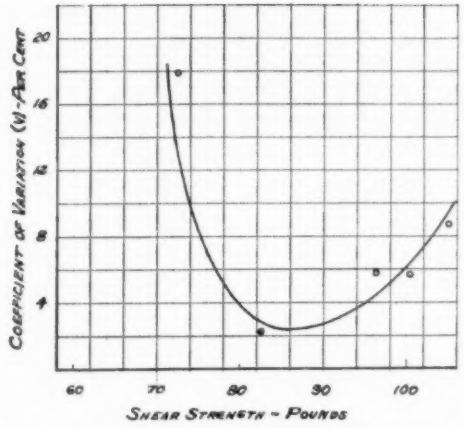

Fig. 3 Variation vs. shear strength of spot welds in 0.012–0.012-in. Alclad 24S-T3

comfort; in order to provide a safety factor, it is suggested that this figure be raised to 95 lb., where consistency is still good, according to the curve.

In Fig. 4 are shown the macrostructures of welds representing the five strength levels; note that all have good penetration.

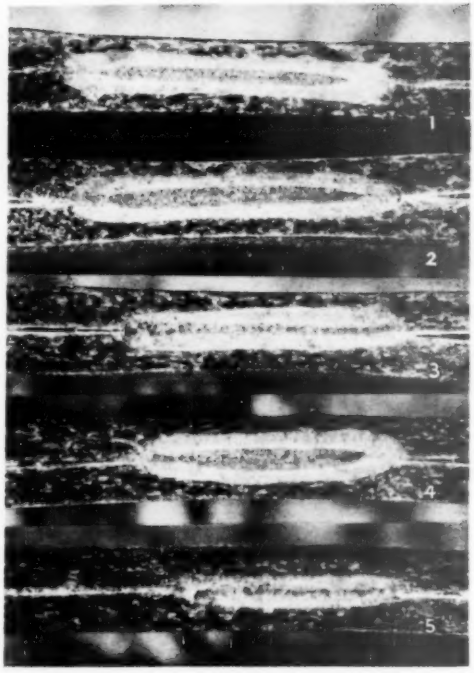

Fig. 4 Macrostructures of spot welds in 0.012–0.012-in. Figures to the right refer to schedule numbers, Table 6

0.020–0.020-In. Combination

For the 0.020–0.020-in. combination a medium size Taylor-Winfield Hi-Wave was selected, and it was decided to weld this group with a double pressure cycle. Table 7 gives the schedules and test results, and the consistency-shear strength curve is plotted in Fig. 5. From the curve an optimum strength of about 185 lb. is derived.

The general level of consistency of this combination is not too satisfactory, as the best coefficient obtained was over 6%. It is felt that this might be partially due to the use of low welding forces, which were close to the minimum obtainable on the machine, and which may have varied for this reason. Furthermore, there appears to have been some change in welding conditions during the making of Group 4. For this group the first half of the welds averaged at a higher strength than did the second half; this transition was so obvious and abrupt that a change in welding pressure or heat seems to have occurred. For this reason it is believed that Group 4 was in reality somewhat more consistent than shown.

To determine whether spot welds in this combination are prone to inconsistency or whether the improper schedule or machine was used, one group of 74 welds

Table 7—Welding Schedules and Consistency Data

(Machine: Taylor-Winfield Condenser Discharge, Medium Size, Air Actuated, Type HWRD 36-3)

Gage combination, in.	Schedule No.	Tip force, lb. Weld	Tip force, lb. Forge	Voltage	Capacitance, mfd.	Turns ratio	Time delay to forge, millisec.	Electrodes: Diameter, in.	Electrodes: Contour dome radius, in.	Average shear strength, lb., $\bar{X}$	Number of welds, n	Standard deviation, lb., σ	Coefficient of variation, %, V	Spot diameter, in.
0.020–0.020	1	200	320	2525	120	300:1	20	3/16	2 1/2	248.7	72	22.2	8.93	0.120
	2	150	250	2350	120	300:1	20	3/16	2 1/2	208.7	72	16.7	8.00	0.110
	3	150	250	2250	120	300:1	20	3/16	2 1/2	193.3	72	13.2	6.83	0.105
	4	100	160	2100	120	300:1	20	3/16	2 1/2	188.5	70	14.4	7.64	0.095
	5	100	160	1950	120	300:1	20	3/16	2 1/2	146.9	72	14.0	9.53	0.090
0.064–0.064	1	1300	3400	2650	840	450:1	65	3/16	4	1304.9	67	70.6	5.41	0.250
	2	1200	3100	2625	720	450:1	60	3/16	4	1052.2	65	56.6	5.38	0.230
	3	1100	2800	2525	720	450:1	55	3/16	4	1027.1	67	40.4	3.93	0.215
	4	1050	2700	2550	720	450:1	55	3/16	4	966.7	65	33.0	3.41	0.215
	5	1000	2500	2500	600	450:1	50	3/16	4	798.9	67	40.9	5.12	0.200
	6	900	2300	2650	480	450:1	50	3/16	4	679.9	67	33.9	4.99	0.190

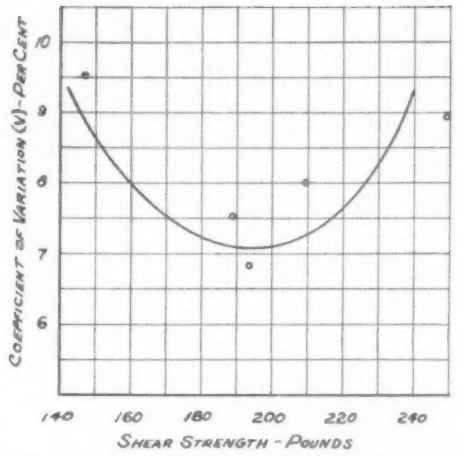

Fig. 5 Variation vs. shear strength of spot welds in 0.020–0.020-in. Alclad 24S-T3

was made on the small motor-operated Taylor-Winfield machine, Type HWRD Style 4, at a shear strength level close to the optimum of 185 lb. The following weld schedule was used:

Electrode contour	2½-in. R dome
Tip force	475 lb.
Capacitance	240 mfd.
Condenser voltage	1775 v.
Turns ratio	300:1

This group of welds had an average shear strength of 178 lb. and a coefficient of variation of 4.15%. This low coefficient shows that it is possible to weld 0.020–0.020 in. with good consistency, and that our choice of machine or pressure cycle was faulty. We do not believe a change to another machine would alter the optimum strength level. This contention is borne out by the average shear strength of the group last mentioned, which is close to the optimum strength of 185 lb. and which has a good consistency.

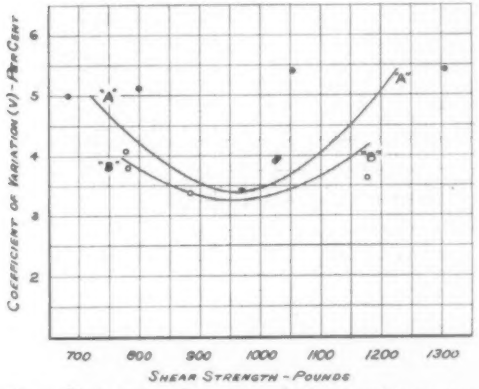

Fig. 6 Variation vs. shear strength of spot welds in 0.064–0.064-in. Alclad 24S-T3

Curve A, medium-size Taylor-Winfield Hi-Wave
Curve B, large-size Taylor-Winfield Hi-Wave

0.064–0.064-In. Combination

Two sets of welds were made on the 0.064–0.064-in. combination, one set on the medium and one set on the large Taylor-Winfield Hi-Wave welder. For the medium machine, this combination was close to the thickest allowable, while for the large machine, it approached the lower thickness limit. In this way the top limit of one machine could be compared directly with the lower side of the other machine; if, under such conditions, the optimum fell on the same point for both curves, we should obtain good corroboration of our theory.

Tables 7 and 8 and Fig. 6 contain the necessary data for this combination. It is observed that the low point (i.e., the optimum) is at the same strength level in both curves and is about 950 lb. It is noticeable that low variation occurs over a greater range when the large welder is used in preference to the medium size. It is postulated that this occurred due to the fact that more inconsistency would be expected toward the top thickness limit of a machine than comfortably within its range.

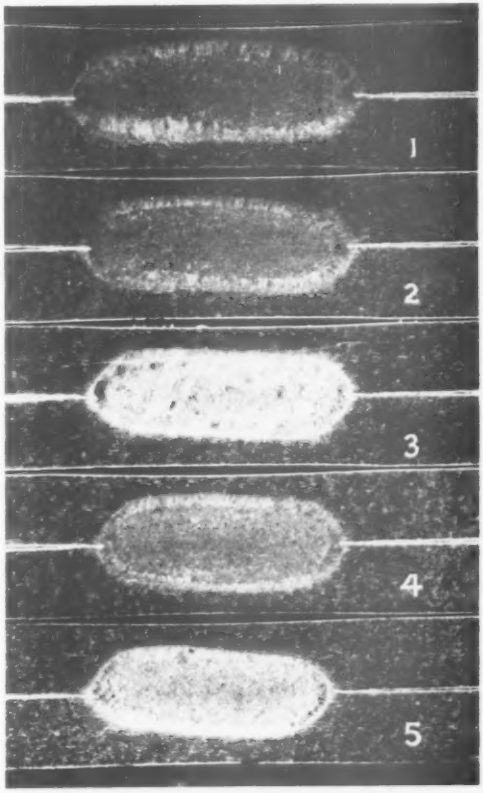

Fig. 7 Macrostructures of spot welds in 0.064–0.064-in. Figures to the right refer to schedule numbers, Table 8.

Table 8—Welding Schedules and Consistency Data

(Machine: Taylor-Winfield Condenser Discharge, Large Size, Hydraulically Operated, Type HWRD 36-4)

Gage combination, in.	Schedule No.	Tip force, lb. Weld	Tip force, lb. Forge	Voltage	Capacitance, mfd.	Turns ratio	Time delay to forge, millisec.	Electrodes: Diameter, in.	Electrodes: Contour dome radius, in.	Number of welds, n	Average shear strength, lb., $\bar{X}$	Standard deviation, lb., σ	Coefficient of variation, %, V	Spot diameter, in.
0.064–0.064	1	1300	3500	2650	960	450:1	95	1½	4	67	1177.7	42.8	3.63	0.265
	2	1200	3200	2600	840	450:1	90	1½	4	64	1024.2	39.9	3.90	0.250
	3	1100	2900	2625	720	450:1	85	1½	4	64	884.3	29.7	3.36	0.230
	4	1000	2700	2400	720	450:1	80	1½	4	65	777.8	29.5	3.79	0.210
	5	900	2700	2550	600	450:1	70	1½	4	66	777.6	31.6	4.06	0.210
0.081–0.081	1	2000	5800	2675	2160	450:1	150	1½	6	53	1894.2	71.1	3.75	0.335
	2	1900	5500	2650	1920	450:1	140	1½	6	60	1608.8	52.9	3.29	0.325
	3	1800	5200	2600	1800	450:1	130	1½	6	66	1471.4	46.9	3.19	0.305
	4	1700	4900	2550	1560	450:1	125	1½	6	66	1246.0	44.7	3.59	0.285
	5	1600	4600	2550	1320	450:1	110	1½	6	67	1094.3	52.2	4.77	0.255
	6	1500	4300	2650	960	450:1	100	1½	6	63	912.1	52.7	5.78	0.225
0.102–0.102	1	2700	8100	2675	3840	600:1	250	1½	6	73	2406	78.3	3.25	0.380
	2	2500	7400	2700	3240	600:1	230	1½	6	73	2197	70.5	3.20	0.355
	3	2100	6100	2650	2040	600:1	200	1½	6	73	1745	62.3	3.57	0.305
	4	1900	5500	2650	1800	600:1	190	1½	6	73	1638	63.8	3.89	0.290
0.064–0.064*	1	1300	3500	2600	960	450:1	90	1½	4	66	1111.7	38.5	3.46	
	2	1300	3500	2530	960	450:1	85	1½	4	67	1030.3	36.9	3.58	
	3	1300	3500	2550	840	450:1	80	1½	4	57	910.8	38.3	4.21	
	4	1300	3500	2600	720	450:1	75	1½	4	67	849.7	33.3	3.92	
	5	1300	3500	2625	600	450:1	70	1½	4	67	670.3	32.9	4.91	

* Constant pressure series.

Macrostructures of welds made on the large machine at the different strength levels are shown in Fig. 7. All the welds are of good shape and penetration.

0.081–0.081-In. Combination

This set of welds was made on the large Taylor-Winfield machine, with data as shown in Table 8. A very satisfactory curve of consistency vs. shear strength, with an optimum shear strength level of about 1450 lb., is shown in Fig. 8.

0.102–0.102-In. Combination

Here also the welds were made on the large Taylor-Winfield machine, with data and results as shown in Table 8 and Fig. 9. It is observed that only four strength levels were studied instead of five; this is due to the fact that condenser trouble was experienced on the last lot welded, which was at a strength level between Lot 2 and Lot 3. Consequently this lot had to be discarded. Later attempts to fill in the curve were unsuccessful because repair work had been carried out on the machine, and its performance was different than it had been before. Actually, the coefficients of the four lots reported were so uniformly low and their strengths covered such a range that the four points are considered sufficient. It is surprising to find that with a range of from 1600 to 2400 lb. shear strength, the coefficients of variation were all below 4%. One could

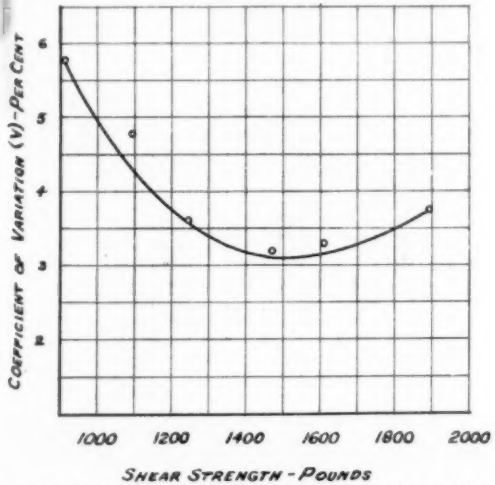

Fig. 8 Variation vs. shear strength of spot welds in 0.081–0.081-in. Alclad 24S-T3

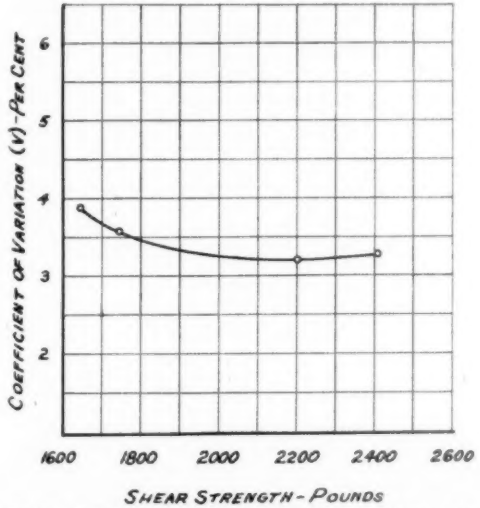

Fig. 9 Variation vs. shear strength of spot welds in 0.102–0.102-in. Alclad 24S-T3

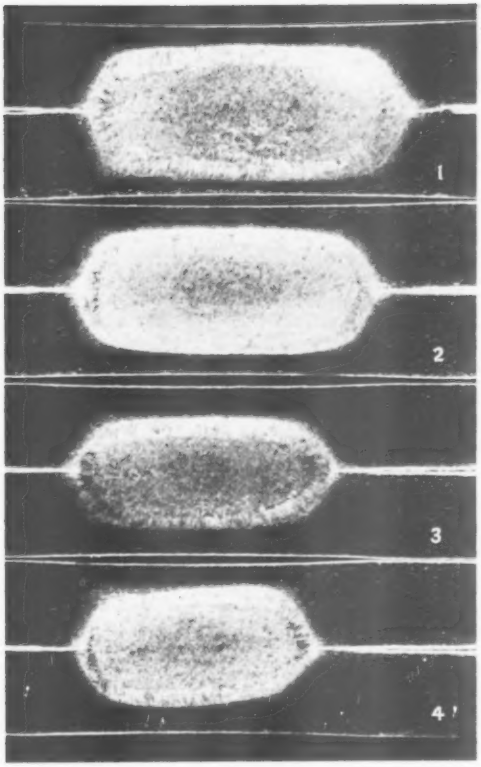

Fig. 10 Macrostructures of spot welds in 0.102–0.102-in. Figures to the right refer to schedule numbers, Table 8

say that it is safe to weld this combination over the entire range studied. Selecting an optimum from Fig. 9 is also very difficult because of the good consistency of all lots. It appears that the bottom of the U falls on a shear strength of about 2150 lb.; this figure was chosen as being most probable.

That welds at all strength levels in this combination were well shaped and of good penetration is illustrated by the macrostructures of Fig. 10.

In studying the consistency curves, one arrives at the following observations:

1. In the heavier gages, 0.064 to 0.102 in., low variation is present over a considerable range of values, at least from 20% below the optimum to 20% above the optimum. This means that considerable latitude could be allowed in the specification of shear values for these combinations.

Table 9—Optimum Shear Strength Levels

Gage combination, in.	*Optimum shear strength, lb.*
0.012–0.012	95
0.020–0.020	185
0.040–0.040	475
0.064–0.064	950
0.081–0.081	1450
0.102–0.102	2150

2. The lighter the gage, the narrower becomes the range of good consistency. Noticeable also in the lighter gages is the greater tendency for loss of consistency as the shear strength is raised. This is probably tied up with the greater tip pickup and change in tip contour, which are associated with larger and hotter welds. At any rate, it is almost as important in these thin gages to keep the strength down to a certain level as it is to keep it above a low, inconsistent strength level. These considerations hold true in gages up to and including 0.040–0.040 in.

ESTABLISHMENT OF THE CURVE OF OPTIMUM SHEAR STRENGTH

In Table 9 are shown the optimum shear strengths of each gage combination, as discovered by test. It is remembered that the value of the 0.012–0.012 in. combination was raised from 87 to 95 lb. to escape any possibility of duds.

The values of Table 9 are plotted in Fig. 11, which is the curve representing the most consistent spot-weld shear strength level for each gage combination. Plotted along with this curve is the AN-W-30 lowest average curve for lots of 20 welds. It is observed that the AN-W-30 curve is remarkably close to the optimum. In other words, if one were to weld at values close to the lowest average allowed by AN-W-30, he would be assured of highest consistency. It is uncommon, however, to do this, because of the danger of falling

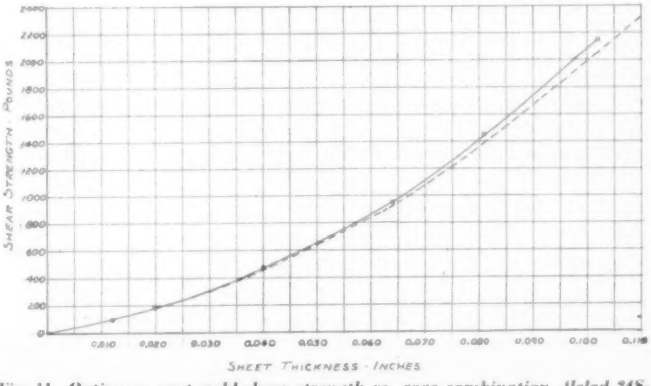

Fig. 11 Optimum spot-weld shear strength vs. gage combination Alclad 24S-T3

Dashed line shows values of AN-W-30 minimum average

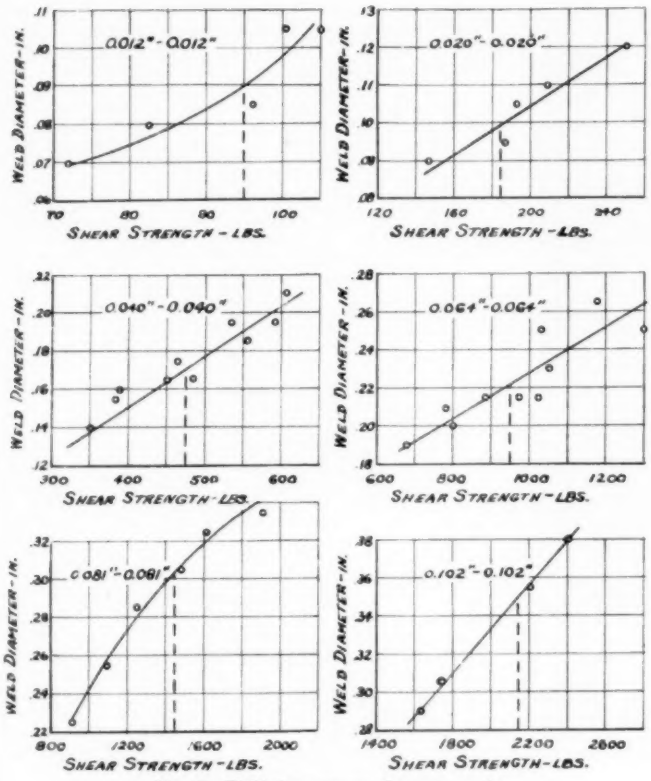

Fig. 12 Weld diameter vs. shear strength

below the line. Instead one is accustomed to weld at levels high enough to insure meeting the specifications; in so doing, consistency is sometimes sacrificed rather than maintained as the Services claim.

We feel that on the basis of Fig. 11 the Services should consider lowering the AN-W-30 minimum average. These new values should be low enough to allow welding to the values of Fig. 14. It is felt that a lowering of 10% would be feasible without endangering consistency. At the same time an inclusion of a note in the specification to the effect that high shear strengths are to be avoided, particularly in the lighter gages, would not be amiss, nor would a note calling attention to optimum values.

OPTIMUM WELD SIZE

The tables containing shear strength values also show the average diameter of the two spot welds selected from each group in each gage combination. The curves showing the relationship between weld diameter and shear strength for each gage combination can be found in Fig. 12. It is noted that there is considerable spread in the curve for the 0.064–0.064-in. combination. This is due to the fact that the welds made on the large machines were of slightly larger diameter, for the same shear strength, than those made on the medium machine. Why this should be so defies explanation, unless the grain size of the welds made on the large machine is coarser and hence the welds are weaker. Also in Fig. 12 a vertical dashed line is located on each curve at the optimum strength level. This line designates the approximate diameter of the welds of optimum strength. These values are plotted in Fig. 13 in two ways: optimum weld diameter vs. gage combination, and ratio of weld diameter to sheet thickness (d/t ratio) vs. gage combination. From the latter curve one can see that for optimum conditions the d/t ratio varies from about 7:1 for the 0.012–0.012-in. combination to about 3.6:1 for the 0.064–0.064-in. combination, and then stabilizes at the latter value for thicker combinations.

THE PRESSURE CYCLE

It was stated in the early part of this paper that the pressure cycle used for any set of welds depended upon the desired shear strength, and that smaller welds (i.e., of lower strength) did not require the weld pressure needed for large welds. We attempted to use a pressure slightly above that at which cracks and internal defects could be made to disappear. All the consistency curves shown here were developed from schedules in which this procedure had been followed.

In order to test briefly the desirability of such a procedure, five sets of welds were made in 0.064–0.064-in. material, at strength levels approximately the same as found in this combination before. The large Taylor-Winfield machine was used, and the pressure cycle was maintained at the same levels (weld and forge) for all sets, regardless of shear strength. The pressures used, naturally, were those necessary to render the highest strength welds crack-free.

The schedules used and results obtained are the last shown in Table 8. From the variation figures shown in the table and from Curve A of Fig. 14, one can see that there is no longer a U curve, but that consistency is better as the strength level is raised. The highest strength level, the only one for which the pressure cycle was properly chosen, is the most consistent. For comparison, also plotted in Fig. 14, is the curve of the 0.064–0.064-in. combination which also appears as Curve B in Fig. 6. This curve represents welds made

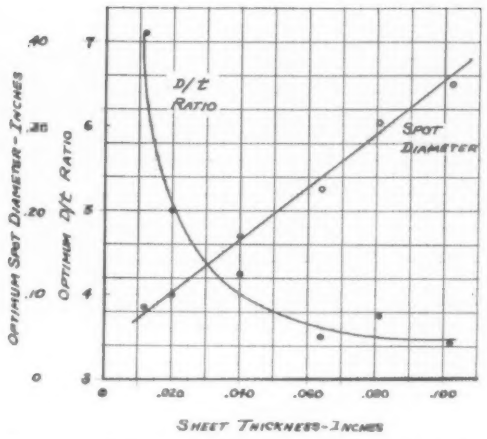

Fig. 13 Optimum spot diameter and optimum d/t ratio vs. gage combination

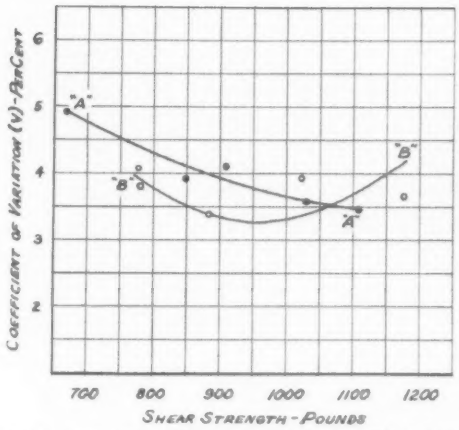

Fig. 14 Variation vs. shear strength of spot welds in 0.064–0.064-in. Alclad 24S-T3

Curve A, tip forces identical for all strength levels
Curve B, tip forces varied depending upon strength level
Large Taylor-Winfield Hi-Wave

with pressures varied according to shear strength level, and gives us the common U curve, in which there is a point of optimum consistency.

Apparently, then, to take advantage of an optimum shear strength level, one must use the pressure best suited to that level, i.e., the pressure just above that necessary to render the welds sound.

A NOTE ON THE MACHINES

The welding machines used for the work outlined in this paper are machines which are used in regular production at the Martin Co. They were not changed in any way for this investigation; it was merely ascertained that they were in good working order prior to use. For this reason, results found herein more nearly represent production conditions than if a laboratory machine were used. Control of variables, such as tip contour and dressing, stock cleanliness and strict adherence to schedule, was of course practiced to a greater extent than possible under shop conditions.

RÉSUMÉ AND CONCLUSIONS

This paper has indicated that for each gage combination of Alclad 24S-T3 there is a shear strength level at which spot welds made in that combination are the most consistent. In order to obtain this high consistency, the values of welding and forge force must be slightly above the threshold at which internal defects disappear; use of very high pressures will result in loss of consistency.

The optimum values of shear strength are very close to the lowest average shear strengths allowed in Army-Navy Aeronautical Specification AN-W-30. This discovery leads us to suggest that these AN-W-30 values be lowered not only to allow working to an optimum value safely above a minimum, but also so that one is not forced to work at shear strength levels which are above those of the greatest consistency. Admittedly this last statement refers more to the thinner than the thicker gages, as the latter maintain good consistency even at high shear strength levels.

Other practical considerations would follow the adoption of these optimum values, since they are lower than the values used now as shop averages. The thickness range of welding machines would be increased, there would be less chance of obtaining defective welds, and qualification and certification, particularly on the heavier gages, could be accomplished more easily.

The investigation outlined and discussed here could be extended to cover other aluminum alloys, as well as steels and other materials. The information obtained would help to raise the quality of spot welding in general.

ACKNOWLEDGMENT

The author wishes to acknowledge the help given to him by J. G. Rutherford, Assistant Chief Inspector of The Glenn L. Martin Co., in interpreting the data statistically. Also for assisting the test work and preparation of the paper, the author thanks C. P. Cowell, Metallurgist, and V. Kilkowski, Jr. Metallurgist, both of the Martin Co.

Fig. 1 Elevation of the bridge

Welded Deck Girder Highway Bridge

Design and construction of a modern welded deck girder highway bridge results in considerable savings. Prefabrication of parts resulted in further savings

by Ned L. Ashton

THE bridge described in this paper is the new Benton Street Bridge across the Iowa River in Iowa City, Iowa, as shown in Fig. 1.

It is a symmetrical five-span continuous steel deck girder highway bridge of welded design, 480 ft. long between abutments and supported on four intermediate concrete piers. The span ratios are 78–100–120–100–78 ft. dictated by both economy and the fact that the western bank pier is located straddle of a twin 14-in. cast-iron sewer siphon running across the river at such an angle as to clear the base of the next pier 100 ft. away, while the 78-ft. end span just clears a sewer manhole at the western terminus of the siphon.

Since this arrangement also located the central 120-ft. span in the middle of the river these requirements determined the final symmetrical five-span layout for the bridge.

The project replaces the old truss bridge which is shown in the background of Fig. 1. The old bridge was located just upstream from the new. It was built originally in 1902 and was finally condemned as unsafe for traffic in 1944.

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This paper is scheduled for presentation at Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

The new bridge was financed entirely as a special bond issue by the City of Iowa City, Iowa, under the leadership of Mayor Preston Koser and the City Council. The total project cost, including the right of way and both approaches, was $276,000.

The new project began with the election of the new Mayor and City Council in the spring of 1947 and with a formal application for a loan of planning funds, from the Federal Bureau for advancing funds and facilities for planning community improvements. The loan was granted immediately, final surveys were made and then several alternative locations and span arrangements were studied, including both the replacement of the existing bridge on the same site and a third alter-

Fig. 2 Cross section of the bridge

nate crossing a little farther downstream. The layout shown in Fig. 1 was finally adopted and final design began in August 1947 pending only the taking of borings to determine the final elevations of rock for the foundations.

The decision to adopt a welded design was made in the beginning since it is the best modern method of joining metals and it offers a considerable economy of material.

The structure provides for two lanes of highway traffic on a 24-ft. concrete roadway and for pedestrian traffic on one 5-ft. sidewalk on the upstream side of the bridge as shown in Fig. 2. Parking facilities are provided on both approaches on the downstream side of the bridge.

The pedestrians are separated from the highway traffic by a steel safety curb and a steel refuge sidewalk is provided on the downstream side of the bridge integral with the handrail construction. The clear roadway width is 26 ft. between the faces of the upper curbs.

One of the special features of this design and construction was the prefabrication of all the curbs and handrails in 20-ft. sections. They were completely assembled in jigs and fabricated as single units, as shown in Fig. 3 in the shop and then were erected in the field as shown in Fig. 4.

Figure 4 is a typical 20-ft. section of the roadway curbs and handrail erecting as a single unit complete with the cantilever brackets and the steel edge channel for the roadway slab. The end handrail posts of each section were made of 6- x 3-in. bent plate post sections, with one half welded to each unit, so that they could be first bolted together endways and then field welded around to form a regular H section post. The other field connections consist of temporarily bolting the regular bracket to girder connections and then field welding the permanent connections after final alignment.

Figure 5 shows a welder at work making the final weld around the two half post sections to join the adjacent sections of the sidewalk handrail.

Both handrails were fabricated in a similar fashion. The top section is 6 x 3½ in. at 10.7-lb. bulb angle, intermediate rails are 3- x 3- x 5/16-in. tee sections and the vertical spindles are 5/8-in. square sections alternating two plain and one twisted. Intermediate posts are 6-in. H at 15.5 lb. The sidewalk rail was fabricated integral with the 12-in. at 25-lb. fascia channel to erect as a single 20-ft. unit.

The sidewalk curb, safety curb and edge channel for the roadway slab make up the third prefabricated unit also as shown in Fig. 5. The safety curb consists of a 5-in. channel welded to a 3- x 2- x 5/16-in. angle with posts at 5-ft. centers. The edge of sidewalk support and roadway curb is a standard 5-in. channel anchored to the concrete with 3/4-in. rods, while a standard 7-in. channel at 12.25 lb., anchored with

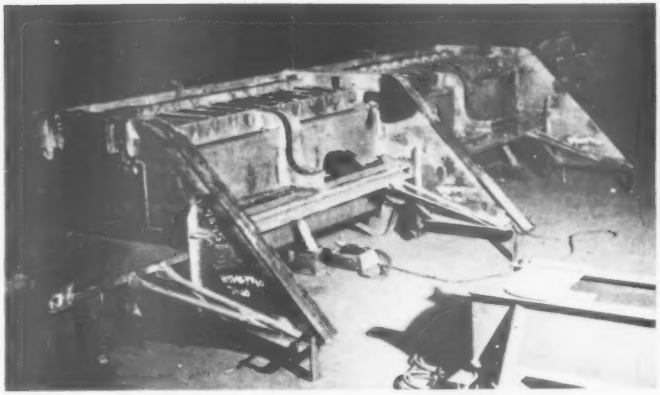

Fig. 3 Prefabrication of handrails in shop

Fig. 4 Erection of roadway handrail and curb sections

Fig. 5 Sidewalk curbs and welder at work on the sidewalk handrail

$^1/_2$-in. trussed rods, is used for the edge of the roadway slab.

The roadway slab is a typical transverse concrete slab of 6-ft. 9-in. span, reinforced with transverse welded reinforcing bar trusses. The trusses are spaced at 6-in. centers, each consisting of four $^1/_2$ in. bars and a $^3/_8$-in. web bar with longitudinal steel as shown in Fig. 6. The roadway slab is $7^1/_2$ in. thick of which the top $^1/_2$ in. is an extra thickness allowed for wear. The sidewalk slab spans 6 ft. from the 5-in. roadway curb channel to the 12-in. fascia channel. It is a $3^1/_2$-in. thick concrete slab except adjacent to the curb where it is thickened to 5-in. for Bell Telephone and electrical conduits that are contained in the slab for the bridge lighting system and for traffic signal controllers.

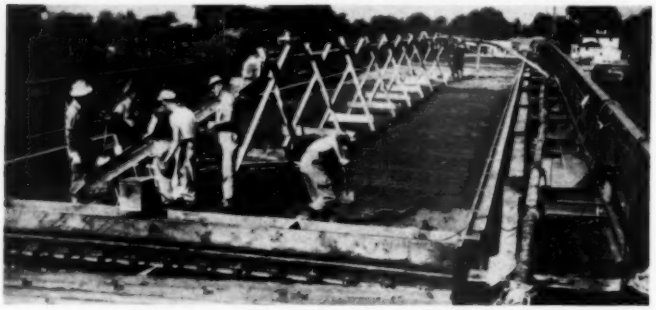

Fig. 6 Details of the transverse roadway slab

Fig. 7 Arrangement of the structural framework

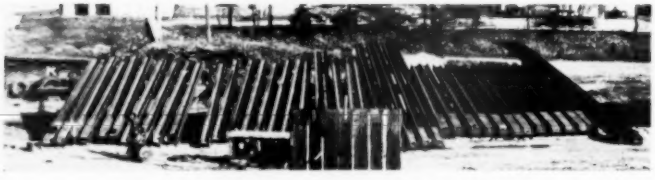

Fig. 8 October 26th—pointing of the piles

The arrangement of the main structural framework is shown in Fig. 7. Floor beams 27WF 94-lb. with the bracket extensions are spaced at 20-ft. intervals throughout the entire length of the bridge except for the first and last end spaces which are 18 ft. The floor beams are supported by the main girders which are located under the edges of the roadway slab. The girders are spaced at 20-ft. 3-in. centers symmetrical about the center line of roadway. The floor beams in turn support two lines of 18-in. WF 50-lb. stringers that run continuously over the floor beams, directly under the slab throughout the entire length of the bridge. A temporary lateral bracing system consisting of 5-in. structural tees with bolted connections is also provided throughout the entire length of the bridge in the plane of the bottom flange of the floor beams.

The two main girders are quite similar except for the sidewalk, roadway curbs and bracket details and except for the width of the flanges. The girder flange plates on the sidewalk side of the bridge are 18 in. wide whereas those on the other side are only 14 in. wide due to the lighter design loading.

The main girders are designed as continuous beams on hinged supports with fixed shoes over both center piers and with expansion shoes on both the end piers and on the abutments. The piers and the abutments are all founded on steel foundation piles driven to rock.

The borings for the piers were made in September 1947 and all of the foregoing details were worked out on the design drawings and plans which were completed ready for bidding by February 1948.

Bids for the project were received on April 19, 1948, with the Jensen Construction Co. of Des Moines, Iowa, low bidder with a bid of $257,817 for the entire project, including the removal of the old bridge.

The contract was awarded immediately and construction was scheduled to begin as soon as satisfactory delivery dates could be determined from the superstructure fabricator. This contract was sublet to the American Bridge Co. and delivery of the superstructure steel was scheduled for December 1948. Steel sheet piling was not available at all and delivery of the steel foundation piles was scheduled for rolling in September.

Accordingly, actual construction operations of building the main piers and abutments began at the site on October 2, 1948. Of special interest to the welding engineer are the armored points, splices and caps that were formed on the piles by welding. Figure 8 shows the setup for the pile armored pointing operation in the yard as of Oct. 26, 1948. Steel plates, $^1/_4$ in. thick, were fillet welded in between the H-beam flanges and then bent down between the flanges to form a chisel-shaped point on the piling. After bending down

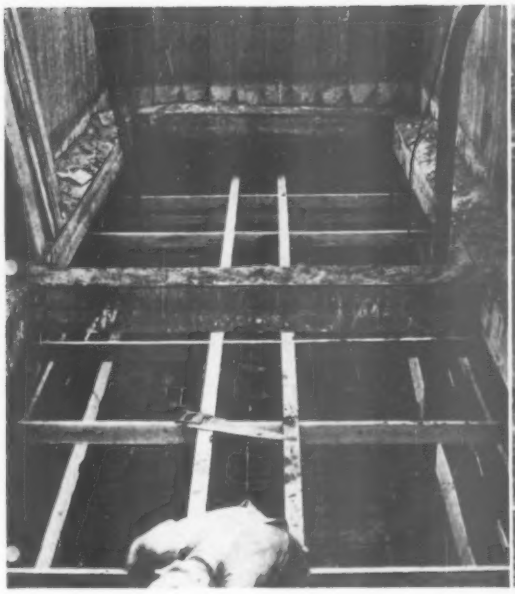

Fig. 9 Welded pile caps

Fig. 10 December 11th—aerial of the piers

and welding to the end of the web the projecting portions of the flanges were removed by flame cutting and the points were filled with concrete for a distance of 5 ft. back from the point.

The point thus formed is intended to reinforce the pile section and prevent damage to the points as they are driven solidly into the surface of the rock and also to provide anchorage against uplift and withdrawal. The piles were driven with a No. 1 Vulcan single-acting steam hammer striking with 15,000 ft.-lb of energy per blow until the average penetration was less than $\frac{1}{8}$ in. in the last ten blows. The piles used were 12-in. BP. at 53-lb. sections on the main piers and 10-in. BP. at 42-lb. piles for the abutments.

The piles were capped as shown in Fig. 9. The caps were formed by first flame cutting pieces from the pile cutoffs and fitting them in between the web and flanges of the top of the driven piles and welding them in place with fillet and butt welds. All welds were made from the top side of the cap piece in the down-hand or straight horizontal and vertical positions. This is a great convenience to the welder as compared to the overhead welding of an ordinary cap plate.

The piers were all sunk on sand islands by means of open wooden sheet pile cofferdams to a depth of about 13 ft. below the water surface. The steel bracing frames were lowered into place as the material was dredged out and the piles were driven from above the water surface. After sealing, the cofferdams were pumped out so that the piles could be cut off and

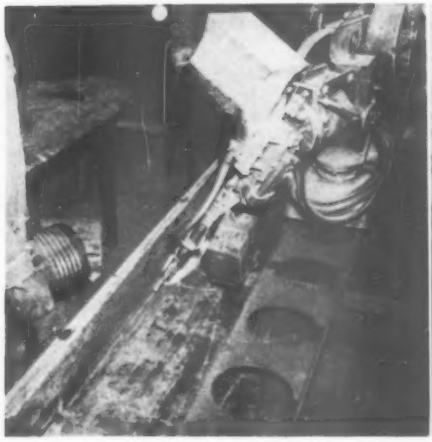

Fig. 11 Automatic welding the girder flanges

Fig. 12 Tee-shaped stiffeners

Fig. 13 Fixed shoe

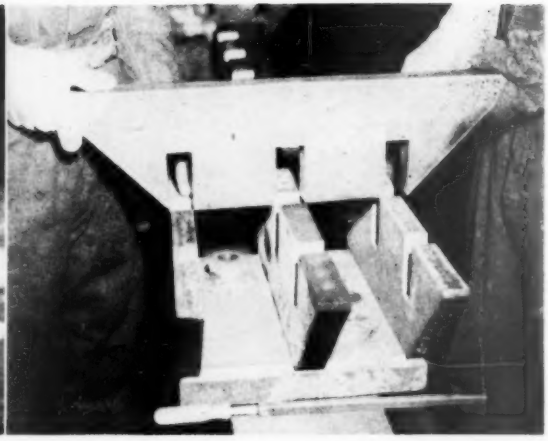

Fig. 14 Assembly of shoes

capped in the dry. The base reinforcement was then placed as shown in Fig. 9 and the regular pier base poured in the dry on top of the seal.

The remainder of the shaft and pier construction was all in the dry and due to the extremely favorable low water conditions in the river all concrete was delivered directly to the pier sites and even to the two intermediate piers in the river by ready mix concrete trucks driven on the sand fill directly to the pier sites.

The progress in the field was so rapid that by Dec. 11, 1948, all main piers were complete as shown in Fig. 10. The two abutments were also poured and ready for steel by Dec. 20, 1948.

Progress in the shop was not quite so good and the first shipment of the superstructure metalwork did not arrive at the site until Feb. 25, 1949.

All steel was ordered into the American Bridge Co. shops at Gary, Ind., for fabrication early in December 1948 and all shop drawings were completed and approved as of Dec. 4, 1948.

The main girders were all fabricated by automatically welding three plates together with the hidden arc process as shown in Fig. 11.

As special features these girders introduce the use of double structural tee-shaped bearing stiffeners forming an H section column for the reaction at interior supports, and they also feature single structural tee-shaped intermediate stiffeners spaced at 5-ft. centers located on only the inside faces of the girder webs, as shown in Fig. 12. The stiffeners were notched on a 2-in. radius at the junction of the web and flange to avoid the three-dimensional restraint of stresses in the corner and also for drainage.

During fabrication of the girders the transverse warpage of the 18-in. flanges amounted to approximately an angle change of $^3/_8$ in. in 9 in. This was compensated for by postheating the opposite side of the flange plate with another longitudinal bead of heat to shrink it back into the flat position.

The combined effect of both the flange to web welding heat and the compensating bead of heat was to cause a longitudinal shrinkage of the girder flanges with respect to the web amounting sometimes to as much as an inch in 50 or 60 ft. of length of the girder.

This effect buckled the web plate into a series of longitudinal buckles that sometimes required additional transverse beads of heat across the web to shrink the center of the web plate back into alignment again. This difficulty caused considerable consternation in the shop on the first few girders and one particular girder required three days of an expert heater's time in these postheating and final straightening operations to straighten it out after welding. The final results, however, were all regarded as quite satisfactory.

Part of the longitudinal buckling was also due to a misinterpretation of the shop drawing symbols resulting in $^5/_{16}$- to $^3/_8$-in. continuous welding beads being used on both sides of the intermediate stiffeners on the first girders whereas only $^3/_{16}$-in. fillets were officially called for on the drawings.

In future designs, the author would recommend the use of not less than a $^5/_8$-in. web plate as the minimum thickness for girders similar to these whereas only a $^1/_2$-in. web plate was used throughout in this design. The thicker web would thus have more inherent stability.

The author also wishes to call the attention of the American mills to the special flange plate sections that are rolled with a small projection of web attached for welding flange to web sections that have long

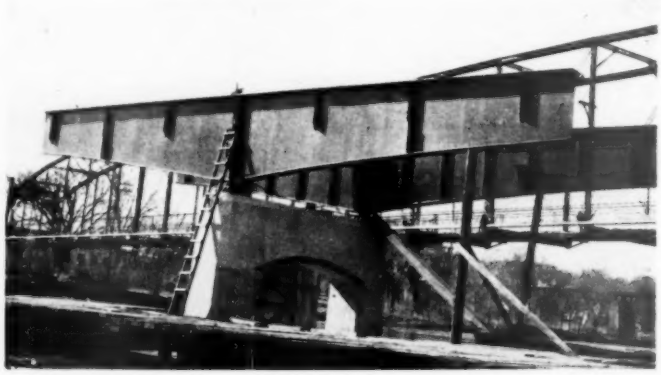

Fig. 15 Erection of girders over Pier 2, Apr. 4, 1949

been standard rolling mill sections in European practice. These sections were designed to help alleviate the shrinkage and warping problems in the flanges, and have been in use for a long time in foreign welded girder construction but they have not yet been made available from our own American mills.

Another special feature is incorporated into the design of the shoes. A typical fixed shoe is shown in Fig. 13 with the pad of high-strength weld metal deposited on top of the shoe by manual welding to give high-yield point characteristics in the line bearings. The pad is deposited $^5/_8$ in. thick and then machined and ground down for the bearing surface.

The design of the pedestal is also unique. The crossed webs were formed as shown in Fig. 14. All interior welds were made from the underside and then the whole assembly with the top plate turned over and welded all around the outside to the base plate as shown in Fig. 13. Two $1^1/_2$-inch shouldered bolts extending through the girder flanges were then used to fasten the girders to the shoes at the fixed points, engaged with the nuts that are shown welded to the bottom side of the cap plate on Fig. 14.

The expansion shoes on piers 1 and 4 and on the abutments and all of the sole plates on the main girders were also furnished with pads of high-strength, high-yield-point bearing metal deposited on the surfaces of regular structural plates. The welding rods used for this purpose were Murex Type 90 rods. The specifications called for a minimum yield strength of 55,000 psi. which is equivalent to chrome nickle steel and the final results were quite superior to these requirements.

Probably the greatest advancement in design in this structure is in the design of the girders themselves. Not only were the girders fabricated of three plate sections by welding, but also all of the field connections and the main girder splices were made both in the shop and in the field as 100% penetration butt welds. The depths of the girders vary from 4 ft. deep at the ends to 8 ft. 1 in. back to back of flanges over the middle piers.

The first steel was delivered in Iowa City on Feb. 25, 1949, and the 94-ft. end sections of the girders were temporarily erected somewhat east of their permanent positions, on timber blocking, on Mar. 4, 1949. These sections of the girders are straight parallel flange sections that span from the abutments to the first interior piers and cantilever 16 ft. beyond the pier to the field splice.

It was planned at this time to continue the erection of the girders from the same land fill as was previously used for the pier construction and to erect a second section of girders balanced over the second interior pier and then fill in the gap between with the 50-ft. central section of the second interior 100-ft. span. This proved to be a false start, however, and erection was

Fig. 16 Girders completed to Pier 2 and temporary bridge, April 5th

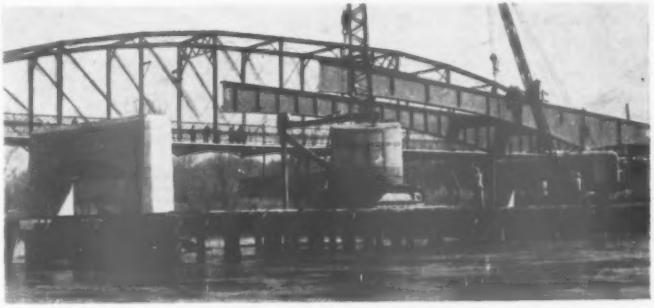

Fig. 17 Erecting girders in Span 3, April 9th

Fig. 18 Erecting girders over Pier 3, April 11th

Fig. 19 Closing section of girders, April 11th

delayed by high water from spring rains and melting snow until April. During this period a considerable portion of the old bridge floor was dismantled and the rest of the steel was delivered. The decking from the old bridge was used to build a new temporary erection trestle to take the place of the sand fill that was lost in the high water.

On Apr. 4, 1949, work started again with the erection of the portions of the girders that were balanced over pier No. 2 as shown in Fig. 15 and by the end of the next day all of the steel was filled in clear back to the east abutment as shown in Fig. 16.

All temporary girder connections were made by means of two $2^1/_2$-in. pins through the webs and the projecting pin plates on the ends of the girders as shown in Fig. 15. This proved to be a very good method of making a strong and simple temporary connection. After first joining the 50-ft. central portion of span No. 2 to the balanced section over pier No. 2 the end sections of the girders were jacked horizontally to join with the other end. After thus being tied to the fixed point on Pier 2 they were lifted from the temporary wooden blocking and set on the permanent roller bearings at Pier 1 and on the east abutment.

As the next step the two central portions of the middle span were erected on April 9th, supported on a temporary falsework bent as shown on Fig. 17.

On Apr. 11, 1949, the variable depth portions of the girders were placed over Pier 3 as shown in Fig. 18 and the final intermediate section of Span 4 was erected between the cantilevered sections to complete the girders all the way across the river. The closure was made on Apr. 11, 1949, by jacking Span 5 horizontally from the west abutment as shown on Fig. 19.

Referring again to Fig. 18, the light colored vertical painted areas on the web are places where it was found necessary to do some additional flame straightening of the girder webs in the field. During unloading operations these panels were found to be from $^5/_{16}$ in. to as much as $^1/_2$ in. out of plane and were straightened by applying vertical beads or areas of heat on the convex sides of the bulges to shrink the metal and pull it back into a plane surface. When the proper amount of heat is applied the metal straightens out perfectly flat without an undue amount of residual stress. It is important to use care, however, because this operation can easily be overdone. The shrinkage forces are as powerful as a stretcher leveling press and will create visible residual slip lines of stress on the surface of a restrained panel of metal or even crack the plates if it is overdone.

Following the adjustment of the main girders for alignment and to grade on the permanent shoes the permanent floor beams, stringers, cantilever brackets and the lateral bracing system were filled in first and then the prefabricated sections of handrails and curbs were added to make the whole structure ready for final aligning and for field welding.

Figure 20 shows two welders at work on the field splices of the main girders in the central 120-ft. span. At this point the girders are 4 ft. $9^1/_8$ in. deep and have 14- x $1^1/_2$-in. flange plates on the south girder and 18- x $1^3/_4$-in. flange plates on the north girder. Both the $2^1/_2$-in. pins and the pin plates were left permanently in the connections and the welds were made by working outward from the center of the web toward the flanges, then the overhead welds in the root of the flange welds and finishing up with the down-hand portions of the main flange welds as shown in Fig. 21. Each one of these main girder splices required about 14 to 16 hr. of actual welders time.

The stringers were furnished in 60-ft. lengths running continuously over the floor beams. They were butt spliced in the same manner at the quarter points of

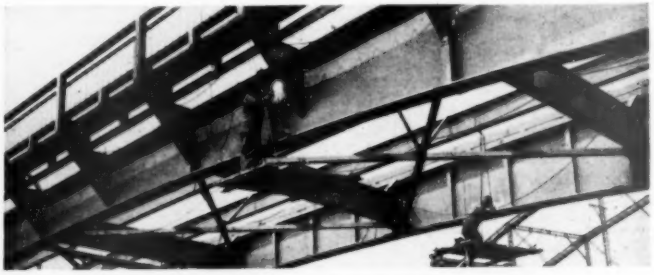

Fig. 20 Welding main girder splices

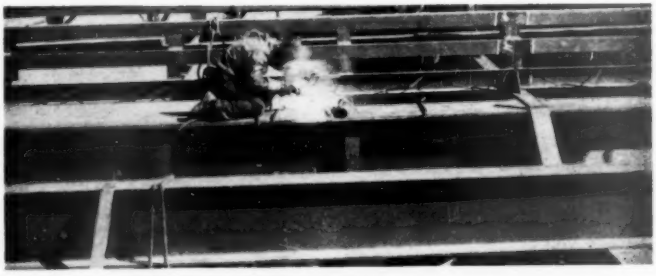

Fig. 21 Welding main girder splice

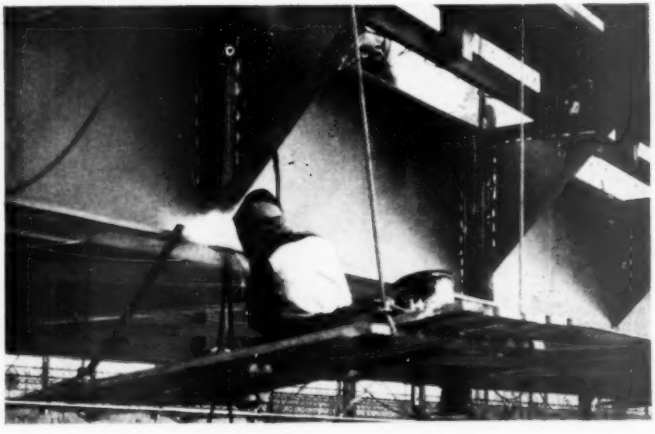

Fig. 22 Welding brackets to girder

Summary of Structural Metalwork

	Unit weight, lb./lin. ft.	*Total weight, lb.*
Sidewalk handrail and fascia	61.5	29,478
Sidewalk curb and edges of slab	48	22,963
Roadway curb, h. r. and brackets	113	54,426
Sidewalk cantilever brackets	25	11,948
Roadway stringers	100	48,024
Floor beams	106	50,802
Expansion joints	14.3	6,884
Lateral bracing	33	16,068
One complete roadway girder	272	130,729
One complete sidewalk girder	318	152,538
Shoes	20	8,594
Miscellaneous light poles, etc.		12,503
Bronze name plates and tape	24.2	116
	1135	545,073

the stringer span. They are also attached to the top of the floor beams by fillet welds.

All brackets to girders and floor beam to girder connections were temporarily made with permanent bolts and then fillet welded as shown in Fig. 22. The top flanges of the cantilever brackets were also strapped across the top flanges of the girder and butt welded to the top edge of the floor beam brackets as shown in Fig. 21.

The field welding for this project was done under a subcontract by the Teleweld Corp. of Chicago and all welders were certified welders qualified under the AMERICAN WELDING SOCIETY Code.

The final details also included the installation of the all-welded toothed plate expansion joints at each abutment and the erection of the welded light poles on the approaches for a mercury vapor bridge lighting system.

These details are more or less conventional except that the American Bridge Co. developed a new technique for fabricating the expansion joints. The most successful method now seems to be to weld all of the supporting angles, tooth web plates and anchor plates for both sides of the joint to the common plate top and completely build the entire joint before cutting the two halves of the joint apart. The flame cutting of the toothed profile is then the last operation and by then the joint is strong enough to avoid all of the usual twisting and warpage.

For this 603,080 lb. of material was charged to this job as purchased from the mill.

Welding wire, 12,486 lb., was used in the shop and 12,990 hr. of direct labor in the shop and 965 drawing room hours were charged against this project by the American Bridge Co.

The field welding required 528 man-hours of welders' time, 320 man-hours of riggers' time, 160 man-hours of foremen's time and 1485 lb. of electrodes of which it is estimated that there was about a 10% waste. The actual subcontract cost of the field welding to the Jensen Construction Co. was $4100 and it required approximately 4 weeks of time for the whole bridge.

The final price paid to the American Bridge Co. for furnishing the superstructure steel was 14.2¢ per pound as paid by the Jensen Construction Co. This price was increased from an original bid price of 13.27¢ per pound due to an escalation clause in the contract.

The temporary erection bridge required 8 days to build and cost the Jensen Construction Co. $1400 in labor and $600 in new material such as piles and pile caps. The rest of the material was salvaged from the old bridge. The removal of the temporary bridge required 2 days with four men and a small crane and jet pump. In all it required 970 man-hours of time to build it and then disassemble.

The field painting of the superstructure metalwork was also by subcontract for $1250 with the Jensen Construction Co. furnishing the paint.

The general contractors labor costs on the project were divided between the substructure and superstructure for the main bridge as follows:

	Substructure, man-hours	*Superstructure, man-hours*
Foreman	753	1042
Crane operators	859	635
Carpenters	818	1010
Laborers	1950	3331
Welders	154	By contract
Total	4534	6018

Total for main bridge, 10,552 man-hours

The actual contract cost of the main bridge to the City of Iowa City, exclusive of the approaches but including the removal of the old bridge, was $221,928.66 summarized as follows:

Fig. 23 Expansion joint detail

Item 1	Steel foundation piles	126,441	lb. at $ 0.138	=	$ 17,448.85
Item 2	Concrete in pier bases	261.6	cu. yd. at $83.90	=	21,948.24
Item 3	Concrete - pier shafts and abutments	399.9	cu. yd. at $52.50	=	20,989.50
Item 4	Concrete in floor	273.2	cu. yd. at $52.50	=	14,343.00
Item 5	Reinforcing steel	141,768	lb. at $ 0.154	=	21,832.27
Item 6	Structural steel	545,073	lb. at $ 0.23	=	125,366.79
	Total contract cost of main bridge				$221,928.66

The project was designed by the writer while acting as a private Consulting Engineer for the City of Iowa City, Iowa, field supervision was by Fred Gartzke, City engineer, and the writer and the actual construction was by the Jensen Construction Co. of Des Moines, Iowa, with C. A. Jensen acting as their project superintendent. The project was formally dedicated and opened to traffic on July 28, 1949 and the final contract cost of the whole project was only $252,000.00.

Double-Headed Fixture Welds Both Ends of Tank at Same Time

IN STREAMLINING his production line, this Southern manufacturer of small-sized propane tanks doubled the capacity of the end-welding stations by using two "Unionmelt" heads to weld both ends simultaneously.

The fixture shown (Fig. 1) was designed and built by the tank manufacturer. Both welding heads are attached to the fixture with a hinged bracket and an adjustment screw so that the welding rod can be accurately positioned over the seam. The control boxes are mounted in front of the fixture below the welding heads. A single start-stop switch controls the welding generators and the motor for rotating the cylinder. The fixture is designed for one-way operation, assemblies are loaded into it on one side and the completed cylinders removed from the other. An air piston holds the cylinder in position and centers it for rotation during welding. The air-control valve is located at the lower right at the front of the fixture. The two Unionmelt welding heads produce smooth, high-quality welds at speeds between 48 and 60 in. per minute—this means that the fixture shown can actually turn out 30 to 40 units per hour.

Welding composition, characteristic of the Unionmelt process, is automatically deposited along the joint and covers the end of the electrode in the welding zone. Part of the composition melts in the welding heat and protects the weld from the effects of the atmosphere. Welding proceeds quietly without flash or spatter and the high current used makes possible the smooth, deeply penetrated welds at high speed.

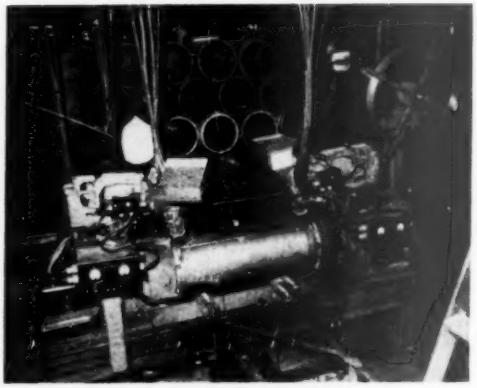

Figure 1

By changing to this double-headed fixture, the manufacturer was able to eliminate one complete station and thus speed up the entire production line.

Data and photo courtesy of The Linde Air Products Co., New York, N. Y.

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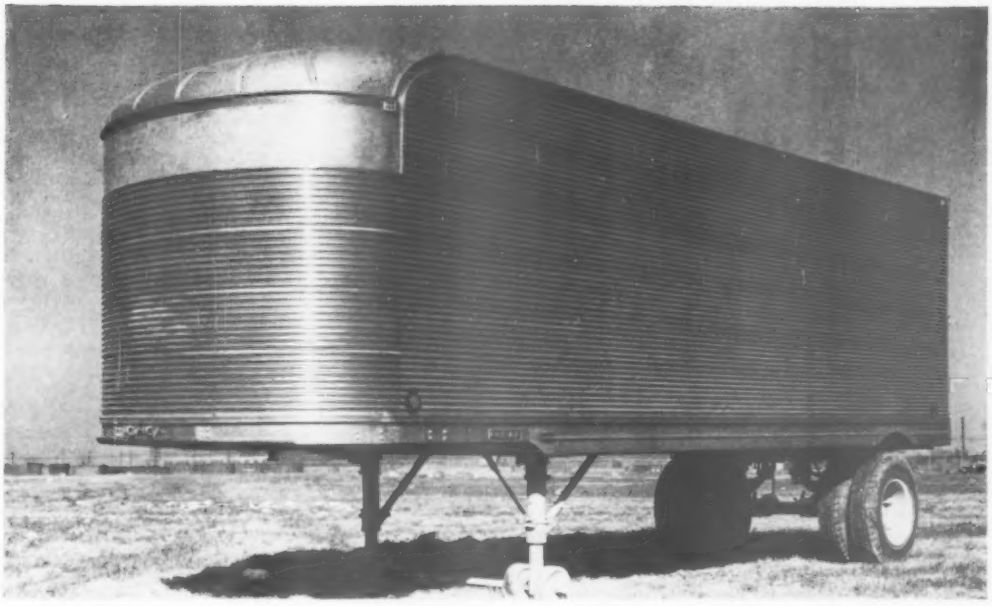

A quarter view of a completed trailer

Resistance Welding Stainless Steel Truck-Trailer Body Components

Assemblies consisting of roof, sides, floor, underframes and doors for stainless steel truck trailers are fabricated by resistance welding and shipped in sets

by Byron Gates

THE resistance welding equipment used to manufacture a product can only be selected after careful consideration of the problems involved. Frequently, simply observing the equipment in operation does not reveal the problems that have dictated the selection of that equipment.

This paper will outline some of the factors that influence equipment selection and note some of the difficulties that arise because of the necessary compromises.

Unquestionably the most important single factor influencing the selection of welding equipment is the original conception of the method of fabrication in the mind of the product design engineer. During the period that the preliminary design is being crystallized it is necessary that the designer and tooling engineers settle details of manufacture because after the design is complete the choice of the method of fabrication for the particular structure has been made.

The final selection of the equipment to be used is a compromise effected by considering many factors. Among the most important of these are:

- The number of assemblies required per shift.
- The anticipated length of time during which the model is to be produced.
- The prospect of additional business of a similar nature.
- The quality that must be maintained to make a satisfactory product.
- The existing equipment that is available.
- The skill of the operators.

The development of the welding tooling used at the Red Lion Plant of The Budd Co., in the manufacture of stainless steel truck-trailer components, is an interesting case illustrating how these factors influenced the selection of the welding equipment now in use.

In 1929 The Budd Co. realized that the strength of 18% chrome and 8% nickel austenitic stainless steel could be increased by cold working from 90,000 psi. to much higher values without lowering the ductility of the stainless steel to a point that it could not be formed into useful shapes.

This realization, coupled with the knowledge that this material is used most advantageously when joined by resistance welding, resulted in the development of the "Shotweld Process" of resistance welding to provide a dependable method of joining structures made of this high-strength corrosion-resistant material.

These two developments—the knowl-

Byron Gates is the welding engineer of the Red Lion Plant of The Budd Co., Philadelphia, Pa.

Scheduled for presentation at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

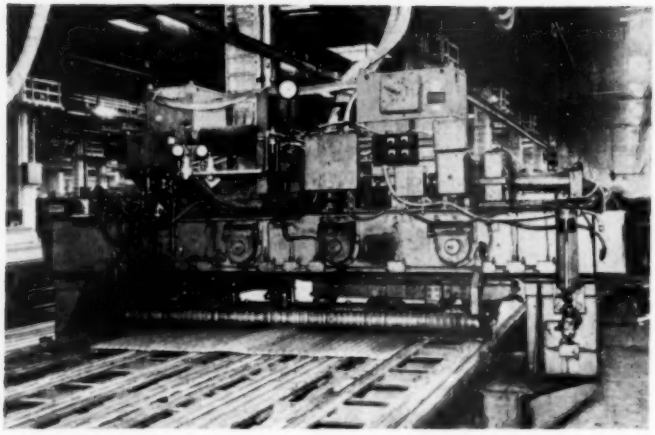

Fig. 1 Sideframe mat welder
This machine makes eight rows of welds at 32 in. per minute

edge of how to make parts of high-strength corrosion-resistant material and the development of a process to join these parts securely and economically—were the first two factors that influenced our present tooling.

The truck-trailers made of stainless steel have been designed to carry a maximum payload in a trailer of minimum weight. The Budd Co. builds the main assemblies of these trailers which consist of a roof, two sides with or without side doors, an oval or square front, floor assemblies, underframes and the doors required for a particular design. These assemblies are shipped from our plant in sets and are assembled into finished truck-trailers by our customer, who welds them into integral units in which each member takes its share of the load.

The problem of manufacturing truck-trailer bodies is complicated by three main factors: The first factor is the necessity of achieving high strength with the lightest possible structure, the second is the wide variation of models required to meet existing state laws limiting trailer size and capacity, the third factor is the necessity of manufacturing small quantities of components for the many models.

These factors dictated that we should provide equipment that was flexible so that model changes would not cause costly delays. The assemblies must be accurate so that our customer can assemble them without difficulty. The production schedules were such that we could not justify automatic machines to manufacture each model, but the quantities of certain components were such that considerable savings could be made where automatic equipment could be used.

Today The Budd Co. is equipped to build components for oval front end trailers and square front end trailers with or without side doors and for single or tandem axles. Our jigs and tooling are designed to manufacture trailer assemblies ranging from 6 ft. $^1/_2$ in. to 8 ft. $3^1/_2$ in. in height and as long as 34 ft. 8 in. in one piece. We are also equipped to build these components for various trailers for five different axle locations.

SIDE FRAMES

The side frames for these trailers are manufactured by making two major subassemblies. The first is a corrugation mat assembly. As the welding involved in this operation is uniform in the location of the rows of welds it was decided that an automatic machine should be made to do this welding. Corrugated strips of metal less than 0.020 in. thick and a top angle of heavier material are placed on a copper-backed fixture where they are held in position by node bars (Fig. 1). The horizontal seams of this assembly are welded by a bridge that advances over the fixture. The bridge is equipped with eight "walking" pneumatic welding guns that are operated by a cam sequence control so that the two transformers are making series welds on four of the eight guns at the same time. This machine travels at approximately 32 in. per minute making welds that are spaced $^5/_8$ in. apart. The machine will make 400 welds per minute. Two fixtures are provided so that two

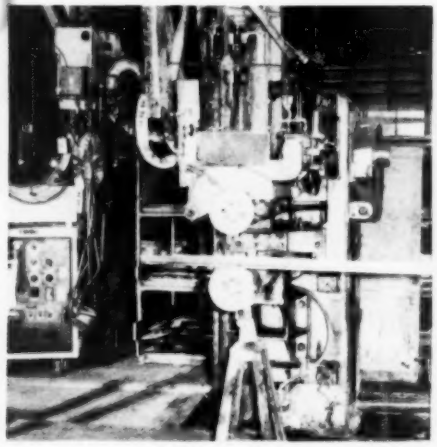

Fig. 2 Stationary roller welder used on trailer-skirt assemblies
In the background is the portable transformer used to partial weld assembly in jig

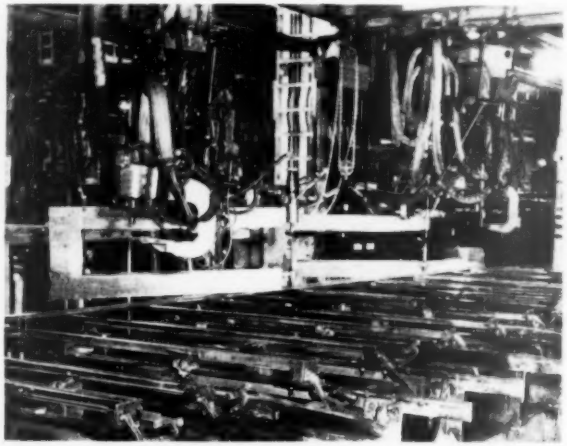

Fig. 3 Portable welding installations used for final assembly of trailer sideframes

models can be made without downtime for jig change-over, or so that one can be loaded or unloaded while the welding is being done on the second fixture. When the welding operation is complete, the corrugation mat assembly is rolled into a coil and stored awaiting the next operation.

The second major side-frame subassembly is the skirt assembly. These skirt assemblies are from 20 to 34 ft. 8 in. long. They are made basically from five formed pieces in a trailer without side doors. A heavily reinforced structure is used as the skirt for a side door trailer.

The various parts that comprise this assembly are positioned in a jig and welded together, with the exception of one longitudinal row of welds which represents the majority of the welding on this structure. This row of welds is made by roller spot welding, placing the assembly on a table equipped with a roller top (Fig. 2) and using a stationary machine to do the welding.

Low production costs with the required flexibility are achieved by the use of portable guns and the stationary roller welder.

The final assembly welding of the side frame component is made using portable tool installations (Fig. 3). The two bridges over the jig each support a transformer and to each of these transformers are attached three guns. A total of five different yoke designs are required for the various clearances on all types of trailer side frames. The vertical posts are placed in the jig, and the skirt assembly is positioned and welded to these posts. The corrugation mat is then positioned and welded to the posts using guns with 58-in. throats. The jigs are of such design that they can be changed to accommodate the varying models in less than 2 hr.

Estimates have been made on having an automatic machine designed and built to do this welding. We have never had such a machine built because these estimates revealed that it would take too long a time to make the required savings in labor to amortize such equipment. This added to the greater possibility of maintenance difficulties and longer change-over time between models dictate that we continue gun welding this final assembly.

ROOFS

The roof mat is of the same general design as the side frame mat. The side angles and corrugated sheets are placed on the same fixtures that are used for the side frame mats. The welding bridge is provided with a high-speed drive and welds are made 1 ft. apart on the seams of this assembly at the rate of 70 in. per minute.

The partially welded mat assembly is next placed on a table and all of the seams are welded using a roller welder (Fig. 4) with two sets of wheels; current for each set of wheels being supplied by a separate transformer. This machine is novel inasmuch as the work is stationary, and the rolls, which are not driven, are moved over the work by driving the entire frame of the machine. The rolls are provided with a steering mechanism to keep the weld on the overlapping seams in a straight line.

The machine was designed to do this operation to secure a watertight roof at low cost. No other method of sealing this roof is comparable for quality. If an attempt were made to weld more than the two seams at one pass the machine would be a much more expensive piece of equipment that would be more difficult to maintain.

The main assembly of the roof is completed using portable gun-welding equipment (Fig. 5). Each of the two bridges over the jig supports two welding guns. The carlines or transverse ribs are positioned and the mat is put in place. The welds between these carlines and the mat are reinforced by the use of a $\frac{5}{8}$-in. square

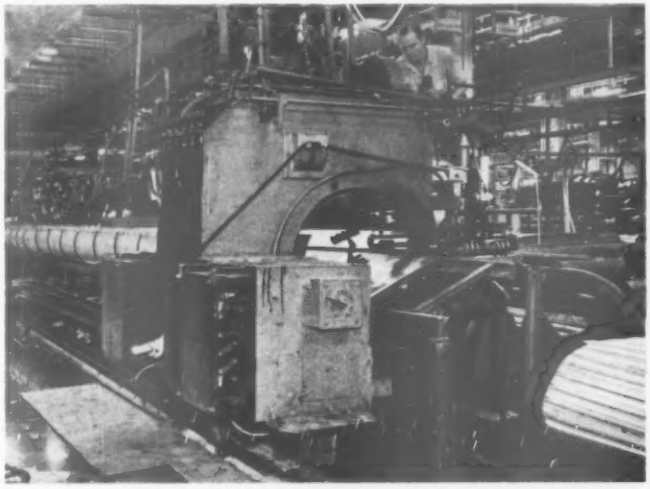

Fig. 4 The roof-roller welder makes welds on two seams at the same time

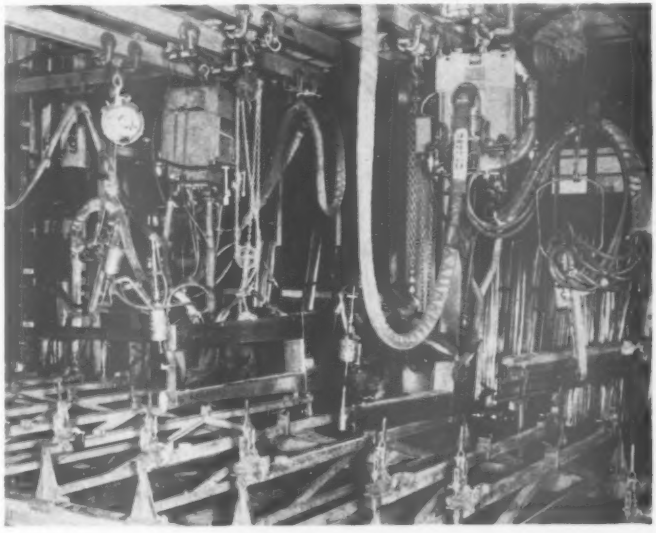

Fig. 5 The portable installations used over the roof jig are similar to the side frame

pad on the top of the corrugation to minimize the possibility of a shifting cargo pulling holes through the corrugation. These doublers make the connection between the corrugation and carline so strong that if the corrugation is hit hard enough to cause failure, a tear in the roof results and not a hole at a weld. Surprising as it may seem, the welding operators have become so skilled in positioning these doublers that we have not been able to develop a hopper feed that does a better or more economical job.

After the welding is complete, the roof is ejected from the jig by pneumatic cylinders and it is slid sideways into a welding pickup station where the front trim angle is applied. At this same station, several inches of metallic arc welding is done to complete the weatherproofing of the roof. The roof is rain tested at a subsequent station and is ready to be shipped to our customer.

Estimates have revealed that a piece of automatic equipment to do this welding would have the same disadvantages as the side frame machine and it would take many years to make sufficient savings to amortize the cost of this piece of equipment, when taking into consideration change-over time and maintenance.

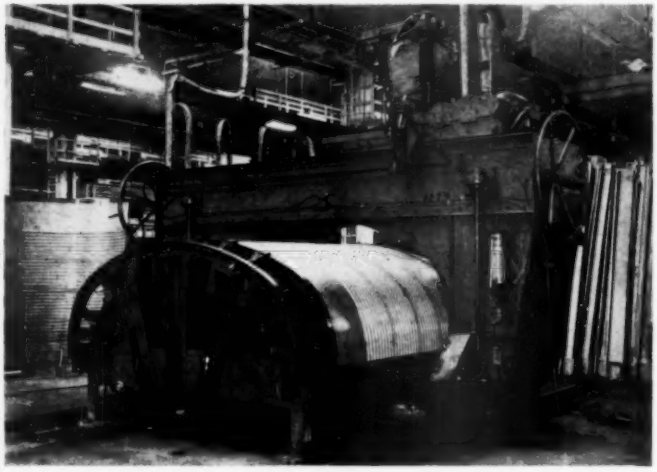

Fig. 6 The oval-front mat welder makes the subassembly of the preformed corrugations

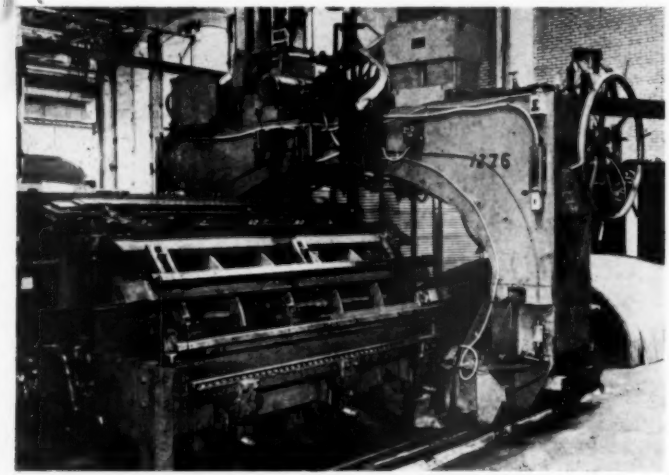

Fig. 7 This machine is used to weld the corrugation mat to the vertical posts

FRONT ENDS

The oval front assembly is fabricated using two welding machines. The first machine makes a corrugation mat assembly (Fig. 6). The preformed curved corrugations and the skirt subassembly are placed in a curved fixture and pulled down to the buss bars by pneumatic cylinders. This machine has two pneumatic guns that make series welds on two parallel seams. The guns are gear-driven around the curved surface and are always at right angles to the surface of the work. The welding current is supplied to the guns by folding buss bars. The change in the reactance of the folding buss bars has been carefully balanced by making a corresponding change in the reactance of the stationary buss bars in the fixture.

The second machine is used to weld the vertical posts to the corrugation subassembly (Fig. 7). This machine has eight guns that make series welds from two transformers. The posts are loaded into a fixture lined with copper alloy back-up bars. The mat is pulled down with pneumatic cylinders to create a close contact between the bars on the fixture, the posts and the corrugation. When the welding is completed the assembly is removed from the fixture and advanced to the next station where portable equipment is used to make heavy welds at the top and bottom of the assembly.

The selection of this automatic front-end equipment was dictated by the realization that the problem of jigging this assembly so that it could be welded with portable tools was difficult. As the welding in this operation is uniform, the most efficient automatic machine was made to do the majority of the welding and the remaining welds are made using portable guns, after the assembly is removed from the fixture.

The square-front trailer tooling was selected for the following reasons (Fig. 8): It is a low production job, and yet its shape makes it difficult to position the parts in a fixture and to use portable welding tools to fabricate the assembly. It was therefore desirable to provide a machine that would locate all of the parts, and do as much of the welding as possible.

The equipment to be designed would provide a means that utilized pneumatic pressure to pull the preformed corrugation down to the fixture in which the vertical posts were located and the corrugation seams were to be backed with a copper-alloy buss bar. The welds in the vertical posts were to be made using portable tools. This decision led to the following problems and solutions.

A bridge structure was made to support a single gun that was guided by two tracks parallel to the welding surface. The gun was mounted on three rollers and was driven by a chain. This design provided a shaft that would rotate $^1/_2$ turn to pro-

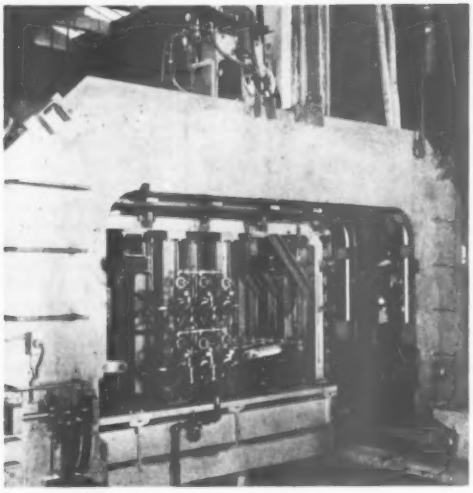

Fig. 8 The square-front welding machine

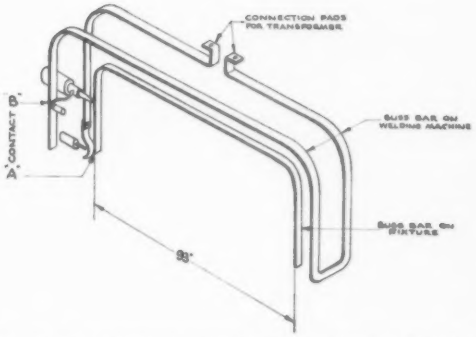

Fig. 9 Buss bar arrangement flat-front welding machine

vide the desired $^{5}/_{8}$-in. spacing on the flat surface. Due to the difference of the radii of the work and the track, this spacing would decrease to $^{1}/_{4}$ in. at each 6-in. radius corner. To overcome this condition it was decided to space the welds on the flat by the cam, and at the corners to electrically disconnect the weld initiation from the cam and substitute an impulse from a cam driven by a synchronous motor. The next problem to be solved arose from the realization that all vertical posts would have two edges. A weld could not be made through the corrugation seams at the edges of the posts or a burn would result because of insufficient backing support. This problem was overcome by placing a switch in the initiating circuit that would open the circuit by contacting stops so that no weld could be made at these points. As can be seen on the illustration the problem of supplying primary welding power, water and air were solved by making a cable of these services and running it over a series of pulleys and removing the excess cable by means of a counterweight. The support used to hold the supply cable from touching the jig on the side opposite the counterweight is carried on the gun carriage.

The next problem was how to supply the secondary welding current to the gun that travels approximately 160 in.; 35 in.

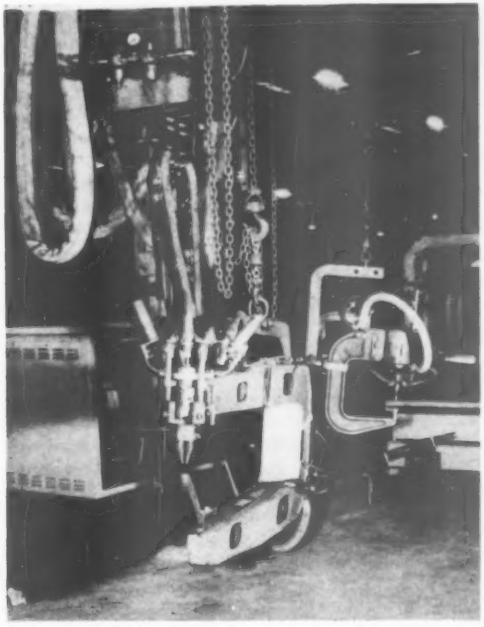

Fig. 10 A portable welding tool with two tips is used on the trailer front end

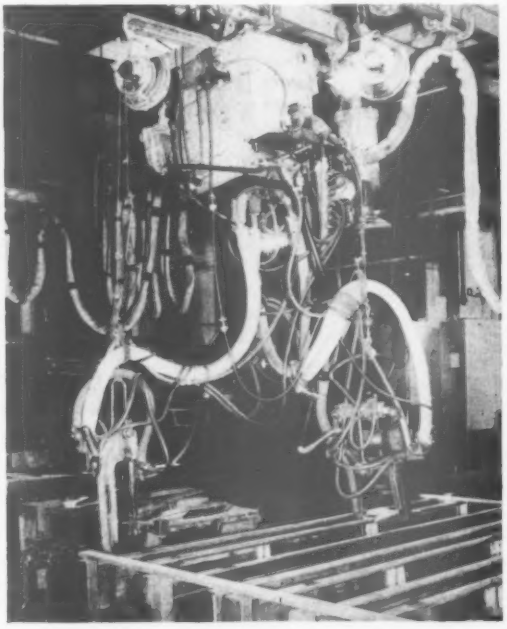

Fig. 11 Portable tools are used to weld the underframe assemblies

up one side, 93 in. across the flat and 35 in. down the other side. It was necessary to have the secondary circuit designed so that the total impedance at all points was the same to stay within the tolerances set by the recorder used in the Budd Shotweld Process of resistance welding.

This was accomplished by using a buss bar in the machine as shown in Fig. 9. In this setup the bridge is moved into position and pneumatic cylinder *A* is used to establish a contact at *A*. Contact *B* is mounted on the gun carriage and makes contact an instant before the weld is made.

This fixture located the parts, and the automatic machine welded all corrugations seams and the posts at the seams. The partially welded assembly is removed from the fixture and positioned under an overhead bridge, where the welding is completed using portable tools. The problem encountered at this operation was that if these welds were made by a gun with a single tip, the weld pattern on the vertical posts would not be evenly spaced. It was decided to use a tool with two tips (Fig. 10). This tool utilized a pressure head that has two small diameter pistons inside the head so that the pressure on each tip is constant. As the weld spacing was too close to permit sound series welds to be made, it was necessary to introduce enough impedance into the circuit so that small resistance changes at the welding tips would not cause uneven distribution of current to the tips.

UNDERFRAMES

The subassemblies of the underframes and the complete assemblies are welded using portable hydraulic guns (Fig. 11) arranged in a production sequence. The various guns required for the operations are installed on bridges that cover the various type jigs that are used.

To manufacture the diversity of types of underframes required precludes the use of automatic equipment to make this assembly. Therefore, we have arranged five overhead installations that permit us to manufacture underframes at low cost.

DOORS

The rear door is fabricated by two men using three overhead installations. The side door is built by one man using two overhead welding installations.

To weld subassemblies for the components already described, four pedestal welders, one stationary roller welder and two overhead portable installations are used.

When selecting resistance-welding equipment to make one assembly unit, the solution is simple, use existing and/or improvised equipment. When selecting equipment to make a quarter of a million assemblies, the answer is equally simple. Supply complete automatic equipment wherever possible. Labor savings will cover the equipment cost.

But when the problem is to make a number of assemblies between these two figures, the answer is not so simple because it is necessary to compromise between the two extremes, and the dictionary defines compromise as "a combination of two opposite systems or principles involving sacrifice of a part of each."

Cleveland Has a New Building Code

by J. F. Maine

INCORPORATED into this Building Code are all the provisions of the A.W.S. "Code for Arc and Gas Welding in Building Construction," also the A.I.S.C. Specifications for the "Design, Fabrication and Erection of Structural Steel for Buildings." Thus Cleveland can make use of the advantages of welded construction. We believe that Cleveland is one of the first large cities to adopt welding as a major means of construction.

There had been a continuing pressure from many directions for a revision of the old Code which was adopted in 1926. Early in 1946 the Mayor, recognizing a need for an up-to-date progressive Code, suggested to Cleveland Council that a new Code be formulated. Cleveland Councilman, Steven Suhajcik, because of his practical construction background, was made Chairman of the Council Building Code Committee. The Mayor also appointed Emil Szendy, a local architect, who had had considerable background in code and specification work to draft the new code.

To assist Chairman Suhajcik and Emil Szendy in formulating the new Code, a Joint Building Code Committee of professional architects and engineers was formed. Under the Chairmanship of Professor Leslie J. Reardon of Case Institute of Technology, eight technical societies, including our own, met regularly with Mr. Szendy to review and approve the work as it progressed. As each section was completed, copies were circulated among interested labor and industry groups and private hearings were held before the Cleveland Council Building Code Committee. This continual exchange of ideas between labor, industry and technical groups was in large measure responsible for the successful formulation and final enthusiastic approval of the Cleveland Code.

The new Building Code, which incorporates sections on welded construction, was approved by the Cleveland City Council on June 27th after nearly 3½ yr. of intensive effort by the Council Committee Chairman, Steven Suhajcik and his Committee, also Emil Szendy and the technical and labor groups working with William Guion, Cleveland Building Committee. The Cleveland Sec-

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tion of the AMERICAN WELDING SOCIETY has done much in laying the groundwork for the organization of the Code and in pushing the Code to its final acceptance.

The new Code is progressive Code. It embodies provisions for changes as new developments in materials, fabrication and erection occur. A board of Standards and Appeals has been set up to continually review all proposed modifications and additions to the present Code.

The provisions for the welding of structures in the Greater Cleveland area is covered in the "Iron and Steel Division" of Chapter 169 of *Materials and Methods of Construction*. The welding is included with provisions for riveting and bolting, and thus welding becomes a standard acceptable method of construction. *Welding has come of age!*

The allowable unit stresses as set up in the new Cleveland Code are the same as contained in the A.W.S. and A.I.S.C. Codes for building construction. Provisions for the preparation of material, design of joints, location and size of welds, etc., are all identical to the A.W.S. and A.I.S.C. Standards.

Provisions for qualification of welding operators are incorporated by reference to the standard qualification procedure of the AMERICAN WELDING SOCIETY but with several interesting modifications. For example, a welding operator qualified for field welding of structural steel must not only pass the qualification procedure as outlined in the A.W.S. Code for Arc and Gas Welding and Building Construction, but he must also "satisfactorily complete a written examination given to establish that he is able to read and interpret drawings and is familiar with welding terms and symbols." It is felt by the engineering groups who helped to formulate the Code that this provision would insure to a greater extent carrying out the erection of welded buildings in conformance with design drawings.

Inspectors of welded structures must also be qualified under the provisions of the new Code. Before obtaining a certificate of qualification, welding inspectors must submit evidence to indicate that they have "had actual welding experience or in lieu thereof education and training in the handling of welding equipment and the making of weldments. The minimum acceptable as education and training shall be a 30-day course in an approved school for welding inspectors."

Any professional engineer registered in the State of Ohio, familiar with welded design and construction, can design buildings and welded structures under the provisions of the new Cleveland Code. To assist the Commissioner of Building and Housing, an Advisory Board, consisting of three qualified men, will be appointed by the Director of Public Safety.' This Advisory Board will consult with the Commissioner on all phases of the application of welding to structures as outlined in the various provisions of the new Code.

Although the 1949 Building Code recognizes in a formal way the advantages of welded construction, Cleveland has not been without welded buildings in the past 15 yr. The first welded structure and office building on Carnegie Ave. was erected in 1928, and since that time a number of partially welded and all-welded buildings have been erected here. William D. Guion, Cleveland's Building Commissioner, has recognized for some years the advantages of welded construction and has permitted under careful supervision the erection of some welded structures.

Over the years the Cleveland Section of the AMERICAN WELDING SOCIETY has maintained a standing Code Committee which has worked with the Commissioner in determining acceptable designs and erection practices which made for sound welded construction. The local section, through its regular technical structural meetings, its educational courses, and by passing on information contained in the National A.W.S. Research Bulletins, has assisted the Cleveland Building Dept. These same activities by the Cleveland Section have done much to promote the appreciation and use of welded design by local architects, designers and engineers.

The 1949 Cleveland Code is a great advancement not only in the use of welded construction, but in every field of housing and all types of structures. Experts estimate that construction permitted by the new Code can save up to 10% in construction costs over the construction allowed by the 1926 Code. The new Cleveland Code represents the progressive thinking and energetic action of the Cleveland Council, the Cleveland Building Dept. and the interested technical groups in joint conference over the last $3\frac{1}{2}$ yr. Special tribute is due to Councilman Suhajcik for his fighting spirit in pushing the Code through to completion. Much credit for a successful Code belongs to the Joint Building Code Committee, under Professor Reardon, who all spent many days without pay and with little thanks in formulating and checking word by word the thousands of provisions included in the 800 pages of the Code.

We hope that the new provisions relating to welded construction will do much to encourage its use in Greater Cleveland. We urge all other cities who do not have an adequate Building Code to go forth and do likewise.

Economic Electric Arc Welding

The factors that control the economical use of arc welding are briefly touched upon. One must start with the drawing board, also determine suitable welding machines, electrodes, placement of apparatus and controls. Some method of recording actual welding time is helpful

by S. Oestreicher

ARC welding has grown from a repair tool into a production method within a comparatively short time. In fact the development was so fast that some of the standards for building and selecting arc-welding machines are still based on the original application of repair welding. Maintenance departments and repair shops naturally need tools for the widest possible range of applications. Accordingly, standard welding machines provide generally an output range from 20% of the nominal current rating at 20 v. (average arc voltage) to 125% of the current rating at 30 or 40 v. depending on the type considered. In other words a 300-amp. welding machine will cover an actual workable output range from 60 amp. at 20 v. to 375 amp. at 40 v. This possible variation of welding output in proportion of 1 to 12.5 shows clearly that the manufacturers of arc-welding machines have been rather successful in building an excellent tool for repair jobs. But it is just as obvious that machines built for a somewhat reduced spread in output would be correspondingly simpler in design and or control arrangement.

When industry started using welded parts instead of cast or riveted pieces, the inherent economy normally justified the change-over. Now, without thorough analysis of design and production procedures it is nearly impossible to manufacture welded products profitably, for weldment competes with weldment. Economical arc welding now must start at the drawing board. Parts or whole machines must be especially designed to take advantage of the possibilities of welding. The size of the fillet, the type and size of electrode as well as the correct welding current are determined in the design stage. These design requirements can be met by a wide variety of welding machines. Table 1 gives a cost comparison that shows that the type of welding machine chosen for a given welding task will influence the final cost considerably. Generally speaking, a.-c. welding is often more economical than d.-c. welding; motor generators should be used in preference to gasoline-engine driven sets wherever possible; welding machines that operate close to their rated output will show the best efficiency and over-all return for the investment. In quite a few cases such an analysis will show that it will be more economical to install two welding machines of different output ratings and to operate them close to their rated capacity, than to use one machine at a fraction of its rating for part of the time. The table does not take into consideration the often possible, increase in welding current and electrode size for a.-c. welding. The influence of power factor corrected a.-c. welders on the over-all power fac-

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Table 1—Cost of Making 1/4-In. Fillet Weld

Model	*Cost per 100 ft. of joint—Labor*	*Electrode*	*Power*	*Total*	*Cost per year, 2080 man-hours*	*Power cost per year*
200 amp., d. c., gas engine driven	$7.418	$1.598	$1.841	$10.857	$5017.86	$ 850.95
300 amp., d. c., gas engine driven	7.418	1.598	2.439	11.455	5294.73	1127.35
200 amp., d. c., electric motor driven	7.418	1.598	0.443	9.459	4372.14	204.76
300 amp., d. c., electric motor driven	7.418	1.598	0.505	9.521	4400.80	233.42
300 amp., a. c.	7.418	1.598	0.256	9.272	4285.70	118.33

Conditions:			
Operating factor, %	50	Deposition efficiency, %	71.5
Type of rod	E-6020	Weld rod stub loss, %	15.0
Size of rod, in.	3/16	Direct labor, per hour	$1.65
Cost of electrode, per lb.	$0.085	Cost of gasoline, per gal.	$0.23
Welding amperes	200	Cost of electrical power, per kwhr.	$0.013
Arc voltage	33	Estimated 46,222 ft. per year for 2080 hr.	

Table 2—Time in Minutes to Change Current Setting from 200 to 400 Amp.

Model	—Distance from work to machine, ft.— 0	5	20	50	100
D. C.	0.15	0.20	0.25	0.50	1.00
A. C.	0.20	0.25	0.30	0.55	1.50
Dielectric	0.05	0.10	0.15	0.40	0.90
Remote (motorized)	0.20	0.20	0.20	0.20	0.20
Remote (dielectric)	0.05	0.05	0.05	0.05	0.05

tor of a manufacturing enterprise, too, cannot be disregarded when a.-c. and d.-c. installations are compared.

Welding machines which are to be installed for production purposes can be selected for requirements as prescribed by the design. With this situation in mind the wide possible regulation of the output of welding machines has lost much of its importance when tooling for production of welded parts. Therefore the thought might be expressed that a close cooperation of user and manufacturer of arc-welding machines might lead to installations of "job-rated" units of—let's say—50 to 125% of the nominal rating. Such an output variation still will allow considerable departures from the load conditions that were originally planned. At the same time it will allow a worth-while simplification of the machines and their controls. For smaller installations the use of standard machines is always recommended. The job-rated installations would be of advantage where a considerable number of machines is involved and a large new production setup is considered.

We have seen that the size of a desired weld as well as the size and type of electrodes is determined in the design stage of a weldment. The production cost is established on the basis of the data given on the drawing. One important factor in establishing the cost of the weldment is the over-all efficiency that can be expected for the type of welding that is under consideration. Much of the efficiency depends on the job preparation. A welder doing straight down-hand welding on a workpiece moving past his work place at the correct speed will deposit more metal than an operator who has to perform considerable positioning work and/or overhead welding while he is moving around. Whatever the job preparation, though, it is a known factor and its influence on cost is reflected in the expected over-all welding efficiency. Welding positioners, fixtures, clamping devices, etc., are employed to raise the efficiency.

In order to produce a weldment of the required strength, and within the calculated cost range, the welder must follow the instructions given on the drawing. Those instructions very often are transferred to the workpiece itself to simplify the operator's task. Production control systems have been worked out that make a close check of actual arc time as simple as reading a clock. By these means the users of welding machines made considerable progress in raising the welding efficiency in production. The manufacturers of arc-welding machines, too, have introduced design features that allow more economical welding, but on the whole more improvements are desirable.

The influence of the welding machine and its control arrangement is often an important factor in raising or lowering the welding efficiency.

If the designer of a weldment prescribes the electrode size and welding current for each separate weld, the welding machine must provide control arrangements that allow the operator to follow these instructions, simply and efficiently. Often the operator should have the necessary control right at the working place instead of being compelled to walk back and forth between his working place and the welding machine for each current adjustment. Table 2 gives the results of some time studies and shows the time required by a welding operator to change the current setting. The distance between work place and welding machine as well as accessibility of the controls is of importance for all machines without remote control arrangements. Alternating- or direct-current welders with motorized output control eliminate the "walking time" but still require a considerable "waiting and trying" time before welding with the new current setting can be resumed. It is evident therefore that providing the welding operator with a calibrated output control at the work place will noticeably increase the welding efficiency and welding quality.

The following pictures will illustrate some of the ideas discussed so far. Figure 1 shows an a-.c. welder with electrical output control that allows practically instantaneous changing of the welding current. The picture illustrates welding of a truck frame. The work is positioned to allow down-hand welding through-

Fig. 1 A.-c. welder installation with remote output control

Fig. 2 D.-C. aircraft welder with field control

out. The calibrated remote control rheostat allows the operator to select the required welding current for each seam without leaving his work place. The welder often uses the control as "crater-eliminator" when approaching the end of a weld. For some time d.-c. machines have been available with a limited remote output control by means of field rheostats (Fig. 2). So far, the output control of d.-c. welders by means of a field rheostat is regarded as limited because of the many ranges or steps provided for most machines as a second and necessary means of current adjustment. A recently developed d.-c. welding machine extends this remote control feature over the whole output which is covered

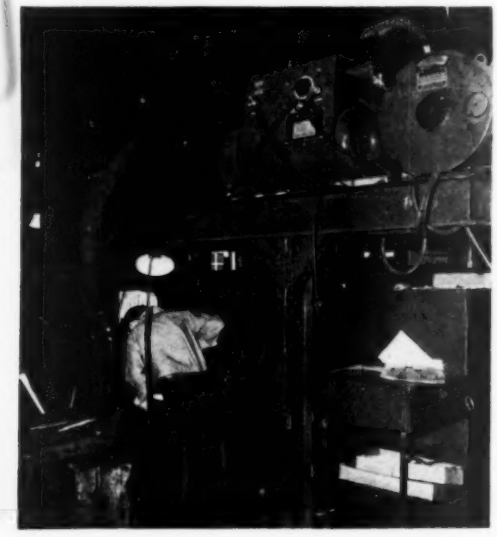

Fig. 3 D.-C. welder with remote output control

Table 3—Actual Operating Efficiencies

$$\text{Eff.} = \frac{\text{Arc time}}{\text{Total time}} \times 100$$

Description of work	*Type of rod*	*Rod size, in.*	*Welding position*	*Efficiency, %*
Crane end trucks	E-6013	1/4	Down hand	57
1/2-yd. revolving frames	E-6012	1/4	Horizontal	55
4-yd. carbody	E-7015	5/16	Down hand	38
Crane box girders	E-6011 E-6010	5/16	Down hand	62
Gears	E-7015	1/4 and 5/16	Down hand	55
Dippers	E-7015	5/16	Down hand	45

by only two ranges or steps. Figure 3 gives a view of such a d.-c. welder installation. This picture shows how valuable floor space can be saved by arranging the welding machines above the work place. The thin wires that also connect to the terminals lead to the automatic arc time control system. The "low" weld-

Fig. 4 Arc time recording system

ing range covers approximately 50 to 200 amp., while the "high" position allows welding from 180 to 400 amp. The operator takes care of the different heat requirements by means of the remote control rheostat. In only a few instances is he compelled to change the setting (high or low) at the machine.

Table 3 shows the wide variation of welding efficiency measured for different jobs. Practically nothing can be done concerning the "burning rate" of the electrodes which are used for the given job. Accordingly, every step to raise the productivity has to be an effort to reduce the time that is spent not for actual welding but for secondary operations.

The welding efficiency is easily checked and recorded by means of arc time recording systems (Fig. 4). Each welding machine is connected to one of the clocks and one pen of the recording meter. Relays arranged inside the clock housing connect clock and pen to their supply line only when actual welding is done. Divid-

Fig 5. A.-C. welder with foot control

ing recorded by actually elapsed time gives an accurate measure of the welding efficiency, and an indication of what should or could be done about it. The psychological effect of the visible record of actual welding time normally is rather stimulating to the weldor. No matter what pay system is used, in the final analysis he is paid for depositing of weld metal and the time required to do so.

Foot-operated output control, especially in inert gas welding installations, made some new and interesting welding techniques possible. These might be discussed separately at a later date. Figure 5 illustrates the use of a foot switch and output control combination that has been widely used in recent installations. The foot control allows current variations during the welding operation. It is rather valuable where overlapping welds are made or changing thicknesses of material are required.

The welding efficiency of many operations in our own plant is considered well above the national average. This successful application of the fundamentals of economical arc welding has been made possible by adhering to them in all phases of welding, i.e., in the design of the welded parts, in the preparation and control of the production and in the design of the welding machines and their controls.

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Welding Metallurgy—Iron and Steel

Due to the large number of papers for presentation at the A.W.S. Annual Meeting, we regret that our September and October issues cannot include the customary chapters of the new edition of "Welding Metallurgy," by Henry, Claussen and Linnert. The next chapter will appear in our November issue

FORTHCOMING installments of the Welding Metallurgy series will include the subjects of "Welding Methods and Processes," "Structures of Metals," "Effects of Alloying Elements," "Welding Plain-Carbon and Low-Alloy Steels" and "Welding Stainless and Heat-Resisting Steels."

"Why weld alloy steel?" The answer is simple and is found in Chapter 13 on page 351 of *Welding Metallurgy* wherein is stated: "Alloy steels containing judicious proportions of alloying elements can be welded with less difficulty than plain-carbon steels producing the same yield strength in the welded part. Stated from a different viewpoint, steels with higher yield strengths (often the determining design factor) can be welded if the strength is secured by alloying elements rather than by high carbon content. Numerous low-alloy, high-yield strength structural steels are on the market containing about 0.10% C which have a yield strength equivalent to a plain-carbon steel containing 0.30% C or more. Yet 0.10% C low-alloy steel has less tendency to harden during welding than 0.30% carbon steel, because carbon has far more effect in causing austenite to undercool than any of the alloying elements."

All of these answers are available to you NOW!!

Send your order today for a complete copy of *Welding Metallurgy*, 6 x 9 in., 500 pages, 203 illustrations, bound in blue cloth for only $2.50.

Joining Wrought Nickel and High-Nickel Alloys

Technical information on the welding and brazing of nickel, Monel, Inconel, "K" Monel, "Z" Nickel and Inconel "X" by all applicable processes are briefly described and the necessary precautions indicated

by K. M. Spicer

INFORMATION contained in many publications[1] has been useful in the selection of material for specific corrosion resistance and high- or low-temperature applications, and has assisted engineers in producing proper designs. Regardless of the careful selection of material and design engineering, the successful completion of a welded structure depends as much upon the skill and knowledge applied on the fabrication floor as it does on the imagination and knowledge applied at the drawing board. This paper will be confined to a discussion of those operations carried out in the welding shop or department.

A brief review of the applications of the high-nickel alloys, which contain 50% or more of nickel, shows that these alloys are used principally for corrosion- and heat-resisting applications where their special characteristics present definite advantages over other metals and alloys.

There are two groups of wrought high-nickel alloys; solid-solution and precipitation-hardening. The solid-solution materials—nickel, Monel* and Inconel*—can be hardened only by cold working and softened only by the application of heat; quenching from elevated temperatures does not cause hardening. The precipitation-hardening alloys—"K" Monel*, "Z" Nickel* and Inconel "X"*—can be hardened both by cold working and by thermal treatment for definite times at temperatures ranging from 1000 to 1300° F. Maximum strength and hardness are obtained by aging heavily cold-worked material.

All base materials are covered by Government or engineering society specifications. To date, specification A.M.S. 5684 has been issued for Inconel electrodes covering composition of deposited weld metal. Joint A.W.S.-A.S.T.M. specifications on all high-nickel alloy electrodes are under promulgation.

Table 1 summarizes the chemical composition and mechanical properties of the high-nickel alloys.

The mechanical properties of these materials range from an approximate low value of 50,000-psi. tensile strength and 15,000-psi. yield strength (0.2% offset) in L nickel* to 165,000-psi. tensile strength and 110,000-psi. yield strength in Inconel "X" when age hardened without cold work. Tensile strengths up to 300,000 psi. have been obtained in Inconel "X" when the aging treatment is applied to heavily cold-worked material.

These alloys are dense materials and have high

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* Reg. U. S. Pat. Off.

Table 1—Wrought Nickel and High-Nickel Alloys

	Nominal composition—principal elements, %					*Tensile properties rods and bars annealed and cold-drawn*					
Material	*Ni*	*Cu*	*Cr*	*Fe*	*Other*	*Yield strength, 1000 psi.*	*Tensile strength, 1000 psi.*	*Elongation, % (2 in.)*	*Hardness, Brinell*	*Charpy impact, V-notch, ft.-lb.*	*Endurance limit 10^8 cycles, 1000 psi.*
Nickel	99.4	...	...	...	...	10–90	65–115	50–15	90–230	222–195	23–45
Monel	67.0	30	...	1.4	...	20–95	70–125	50–10	110–250	220–150	31–47
Inconel	76.0	...	15.0	7.5	...	25–125	80–150	50–15	120–290	230–150	31–51
"Z" Nickel*	93.7	...	...	...	Al-4.4	35–50	90–190	50–7	140–380	240–40	52–65
"K" Monel*	66.0	29.0	...	1.0	Al-3.0	40–130	90–170	45–13	140–320	170–40	34–53
Inconel "X"*	73.0	...	15.0	7.0	Ti-2.5	45–140	110–200	50–20	220–400	−42	−65

* Age-Hardenable.

	MONEL	'R' MONEL	'K' MONEL	'KR' MONEL	NICKEL	'L' NICKEL	'Z' NICKEL	'Z' NICKEL	INCONEL	INCONEL 'B'	INCONEL 'X'
RESISTANCE	X	X	X	X	X	X	X	X	X	X	X
OXY-ACETYLENE	X	X	X	X	X	X		X	X	X	X
METALLIC ARC	X	X	X	X	X	X	X	X	X	X	X
SUBMERGED MELT	X		X		X				X	X	X
INERT GAS SHIELDED	X	X	X	X	X	X	X	X	X	X	X
ATOMIC HYDROGEN	X	X	X	X	X	X			X	X	X

Fig. 1 Welding processes applicable to mill products

melting points and thermal expansion characteristics similar to those of steel. The thermal conductivity of the nickel alloys ranges from that of mild steel to that of stainless steel.

Welding—General

The high-nickel alloys can be welded readily by all the processes common to other materials.[2] Figure 1 shows the welding and allied processes useful for joining. The final service requirements have a definite influence on the selection of the joining process. The high quality of workmanship normally associated with quality materials will be required and demanded by the user regardless of whether the weldments are to be used for subzero, room or high-temperature service.

The highest quality of workmanship includes the necessity for good housekeeping. Cleanliness is of prime importance. All foreign matter liable to contain sulphur, lead or other low-melting materials must be removed from both the welding area and the area that will be heated by welding to avoid embrittlements. Figures 2 and 3 illustrate the typical effects of lead and sulphur. These elements, either singly or together, may be present in grease, oil, machining lubricants, paint, marking crayon or processing chemicals. The foregoing can be reduced to a simple rule: "When fabricating or repairing equipment made of nickel or high-nickel alloys, be certain that all foreign matter is removed from the areas to be welded or heated by the welding operation." If this rule is followed, there will never be any doubt about the procedure to be followed in the repair or alteration of equipment that has been in service.

Good housekeeping includes also the removal of slag or flux from all completed welds or between passes where multiple beads are involved. In some cases this may require the use of sandblasting for complete removal.

WELDING PROCESSES

Metal-Arc Welding

Manual metal-arc welding with flux-coated electrodes is the most universally used welding process for the fabrication of the high-nickel alloys. The same general procedure followed for the production of first quality weldments in mild steel and other materials is used. The only variations are those which are peculiar to alloys high in nickel; a welding speed approximately 15% slower than that used for steel, a shorter arc length and a wider included angle in V-type joints (70 to 75° included angle instead of 60°).

Generally the lower thickness limit for arc welding is 0.050 in., although proper jigging and adequate skill will permit the welding of gages as low as 0.031 in. The jigs used for quality welds in mild steel are suitable for this purpose. Adequate pressure must be supplied to prevent or control movement of the pieces during the welding operation.

The prime purpose of back-up or chill bars is to provide controlled heat transfer and, at the same time, obtain protection from the atmosphere. (A shallow rounded groove in the back-up bar is preferred to a square deep groove. Figure 4 shows both types of grooves; the shallow rounded groove assists in control of penetration and the subsequent weld root contour.)

Welders are familiar with the mechanics of metal arc welding but certain basic factors that control weld

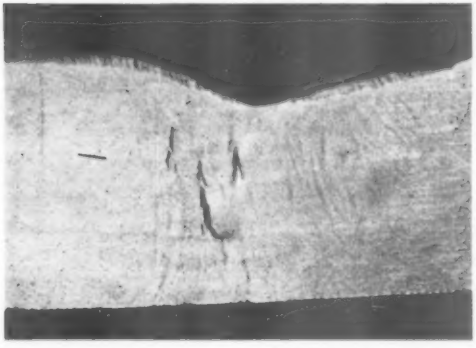

Fig. 2 Typical effects of lead in Monel welds

Fig. 3 Network of cracks caused by sulphur contamination adjacent to the underside of an arc weld on 0.083-in. nickel. Both sides of weld are from the same sheet. Note cracking mainly on right side. Specimen bent to open up the cracks

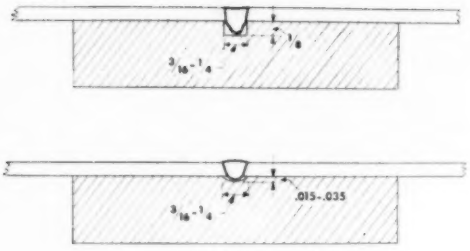

Fig. 4 Chill bar groove design

quality might be reviewed. The first of these is the choice of joint design. Figure 5 shows the recommended joint design for nickel and nickel alloys. The commonly used joint designs for steel are included for comparison.

A square butt joint is recommended only for materials 1/8 in. and lighter. Complete penetration is readily obtained in material lighter than 1/8 in. by welding from one side only; but where complete, uniform penetration is required in 1/8-in. sheet the welding should be done from both sides excepting where backing strips or chill bars are used. Material over 1/8 and through 3/8 in. should be provided with a 75° included angle leaving a 1/16-in. square land at the root. Some welding departments use the V-type joint for material heavier than 3/8 in. but this is not recommended. The V-joint requires more welding electrodes then a U-joint and, of course, more man-hours to weld. Also, it is possible to develop higher internal stresses in V-joints in the heavier gages. The U-joint generally can be used for all thicknesses in material over 3/8 in. The high-nickel alloys are seldom used in thicknesses over 1 in., but where the heavy gages are to be welded, the use of a double U-joint in preference to a single U-joint can be very useful in reducing stresses and subsequent distortion. The V-joint recommended for nickel and nickel alloys has a larger included angle than that recommended for steel and varies slightly in the included angle and root radius. Better quality welds are obtained in nickel and high-nickel alloys if the joint is open to permit the weld metal to be laid in rather than to depend upon high amperages to obtain deep penetration.

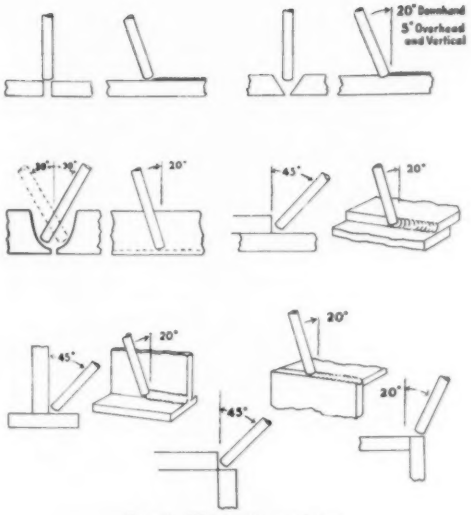

Fig. 6 Electrode positions

The ease of manipulation and subsequent weld quality have a direct relationship to the electrode angle. Figure 6 shows the recommended electrode position for various types of joints. When welding butt joints of either the V- or U-design, the electrode is maintained normal to the joint and is inclined about 20° in the direction of welding. If the joints are in the overhead or vertical position, the 20° inclination should be reduced to 5°. In U-joints requiring double bead layers, i.e., two welds per layer, a 30° inclination from normal is required to obtain the desired results.

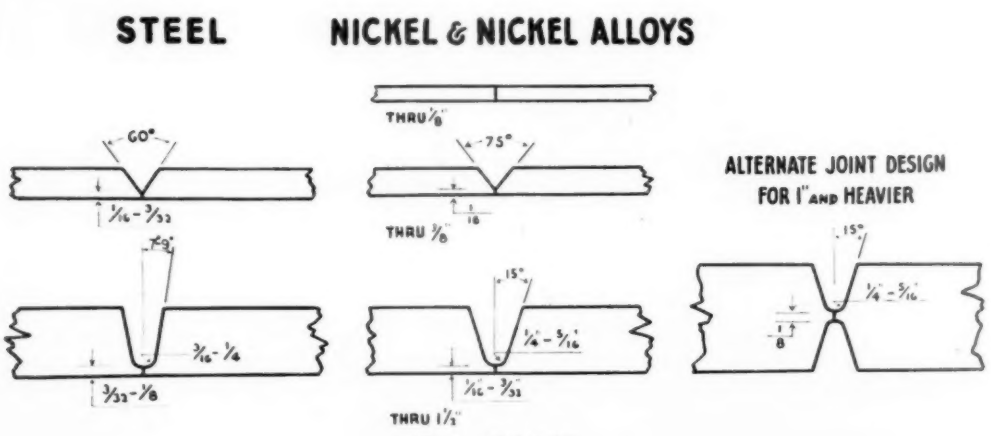

Fig. 5 Joint design

Electrodes are available for the welding of nickel and high-nickel alloys, excepting Inconel "X", in all positions with the same facility as steel electrodes. Table 2

Table 2—Mechanical Properties of Welds in Nickel and High-Nickel Alloys

	Minimum tensile strength	*Minimum yield strength, 0.2% offset*	*Elongation % in 2 in., Min.*
Monel	75,000		30
"K" Monel	92,000	45,000	30
	130,000*	90,000	10
	150,000†	105,000	10
Nickel	72,000		30
Inconel	85,000		30
Inconel "X"‡	105,000§	69,000§	30§
	120,000¶	74,500¶	25¶
	163,800‖, ¶	116,000‖, ¶	23‖, ¶

* Age-hardened.
† Hot-rolled, welded and aged (values at − 300° F.)
‡ Actual test values.
§ As-welded.
‖ Welded with exp. Inconel "X" electrode.
¶ Aged, 1300° F., 20 hr.

summarizes the mechanical properties of welds. Inconel "X" is welded with the electrodes currently available for Inconel. The welds obtained will show considerable response to age hardening due to the pick-up of precipitation-hardening elements from the base material. Inconel "X" electrodes are under development.

There is increased interest in the use of welded and age-hardened "K" Monel vessels, particularly for handling liquid oxygen and nitrogen at subzero temperatures. This interest has been created because "K" Monel is readily welded and the properties obtained in the welds by aging are approximately 60% of those of the aged parent metal. Also, the welds have good ductility and impact strength thus permitting the use of light-weight vessels for many applications. This is of prime importance to the aircraft designer. Minimum properties to be expected in age-hardened "K" Monel welds are 80,000-psi. yield strength, 110,000-psi. tensile strength and 10% elongation.

Development of flux-coated electrodes for the high-nickel alloys presents some problems not encountered with ferrous alloys. Arcing characteristics and bead contour are easy to control with comparatively simple flux mixtures but special attention to the composition of the flux coating is imperative to produce an electrode which will give sound and corrosion-resistant welds.

Electrodes should not be purchased solely on opinion of the welders, based on appearance and weldability. Soundness, corrosion resistance and adequate strength of welds can be the difference between a job which looks good and is good.

If excessive spatter is present when using these electrodes, it serves as an indication that either the arc is too long, the amperage is too high, and in some cases, that the polarity is wrong. Weld metal on nickel and high-nickel alloys does not flow as readily as mild steel, and it is necessary to put the weld material where it is wanted. The arc must contact almost all of the area over which the weld is to be spread. This involves weaving of the electrode and the rule of three should be observed. This rule simply means that the weaving should not exceed three times the nominal electrode diameter. Weaving too widely introduces a possibility of breaking the protective slag or gaseous covering and obtaining a porous weld. Arc blow is not encountered during metal-arc welding of Monel and Inconel and very seldom in nickel. Preheat is neither required nor recommended for arc welding the nickel alloys. Good properties are inherent in the welded joints and no thermal or chemical treatment is needed after welding to maintain or restore corrosion resistance.

When heated in a temperature range of approximately 1000-1500° F., Inconel will undergo a small amount of carbide precipitation both within the grains and along the grain boundaries. This mild precipitation is without serious effect upon the mechanical properties and does not impair the corrosion resistance as in the case of unstabilized stainless steels.

Inconel is a nickel-base alloy and even if some chromium carbide precipitation does occur, the remaining alloy is still principally nickel which in many environments is practically as resistant as the original Inconel. With the iron-base alloys such as stainless steels, carbide precipitation may leave a high-iron material with insufficient chrominum content to maintain corrosion resistance.

The rules covering the fabrication of nickel and high-nickel alloys for approval under the A.S.M.E. Boiler Construction Code has been published in the March, 1949 issue of *Mechanical Engineering* as Case 1074. The important features of this case are permits Par. U-68 and U-69 construction but prohibits U-70, U-200 and U-201 construction.

No stress relief is required on material less than $^3/_4$ in. in thickness for Par. U-68 construction. Thickness limits for stress relieving under Par. U-69 are the same as for steel. Where required, stress-relieving time and temperature are the same as for steel. Very seldom are solid nickel and high-nickel alloy pressure vessels fabricated in thicknesses which will require stress relieving. Test pressures of $1^1/_2$ times the working pressure are permitted.

The case contains a table showing maximum allowable working stress for nickel, Monel and Inconel from subzero to elevated temperatures; however, the upper temperature limits shown in the table are not the limiting temperature at which these materials can be used. They are simply the values permitted for Code approval at this time. The table shows 1200° F. as the limit for Inconel, whereas, this alloy has been fabricated by welding for use in low-stress applications at temperatures above 2000° F.

Where code requirements make stress relief mandatory, it will not have any detrimental effect provided the operation is done in a manner that will avoid embrittlement. This requires removal of all foreign matter and making certain that the heating medium is

sufficiently low in sulphur. Fuel oil should not contain more than 0.5% sulphur and gas not more than 30 grains per hundred cubic feet.

The foregoing is also true for those thermal treatments necessary for age hardening or to provide dimensional stability during precision machining.

Other cases in which nickel and high-nickel alloys are covered are Cases 896 and 1078; these cases outline the rules by which clad steel or lined vessels may be constructed for code approval.

Oxyacetylene Welding

Although the use of the oxyacetylene welding process in the welding of nickel and high-nickel alloys has decreased in the past few years, it is still important for the joining of thin wall, small diameter tubing and other light metal parts which cannot be satisfactorily joined by metal-arc welding. It is recommended that oxyacetylene welding be used for joining all pipe or tubing 2 in. or less in diameter regardless of wall thickness, and for all tubing having a wall thickness of less than $^1/_8$ in. regardless of diameter.

Certain precautions must be followed to insure high-quality results when using this process. The right flux must be used where it is required. Boron-free fluxes must be used. The producers of the high-nickel alloys have developed boron-free fluxes capable of producing welds with the required mechanical and corrosion-resistant properties and they are available through the sources of supply of the base materials.

Figure 7 shows the effect of boron-containing fluxes on the high-nickel alloys. A brittle, eutectic alloy forms at the edges and interface of the weld. The alloy has "brazed out" on the base material outside the fusion zone. Flux is needed for Monel and Inconel, but not for nickel. When welding an alloy that requires flux, it is recommended that a thin film be applied to both sides of the joint and filler wire.

A neutral to very slightly reducing flame should be used with the high-nickel materials. When a neutral adjustment is impractical, the excess acetylene feather should not project more than $^1/_{16}$ in. beyond the inner luminous cone.

If too much excess acetylene is used, particularly with Inconel, there is always a possibility of introducing carbon in the weld and thereby lowering the properties of the joint. The tip of the cone should just touch the surface of the puddle and agitation or puddling should be avoided.

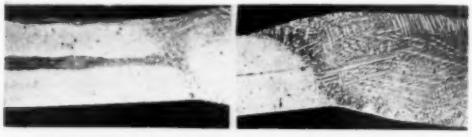

Fig. 7 (Left) Inconel oxyacetylene welded with high-boron flux. (Right) Inconel oxyacetylene welded with boron-free flux

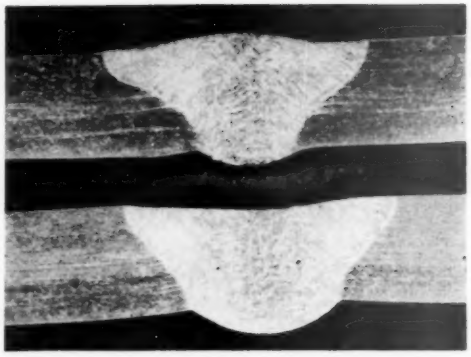

Figure 8

Inert Gas Metal-Arc Welding

The use of this process has shown a phenomenal increase in the past year. It has made possible jobs that were economically or metallurgically impossible a few years ago. No trouble has ever been encountered in the welding of Inconel or Inconel "X" with this process but extreme porosity was present at first in welds made on nickel and Monel when only less pure gases were available. Now that the purity of helium and argon has been brought to a higher level and special filler wires developed, the process can be applied, both manually and automatically, to nickel and the high-nickel alloys and excellent results obtained. Mechanical and corrosion-resistant properties obtained are very satisfactory. Arc lengths should not exceed 0.100 in. for argon and 0.200 in. for helium to obtain maximum weld soundness. Longer arc lengths may be used if some slight, scattered porosity is acceptable. The specially developed filler wires must be used in all cases where filler wire is required. Figure 8 shows cross sections of welds made with the inert-gas metal arc process. Figure 9 is an excellent example of weld ductility.

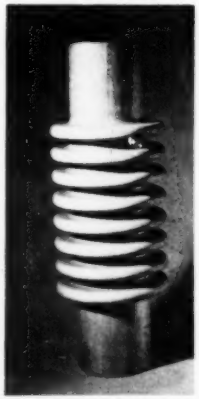

Fig. 9 Inconel X expansion sleeve welded with inert gas matal arc. Corrugated in as-welded condition

Submerged-Arc Welding

The submerged-arc process can be used for the joining of nickel and high-nickel alloys and the weld quality obtained will be in direct relation to the care and control exercised during the welding operation. The presently available melts, or granulated fluxes, are not entirely satisfactory but, as indicated before, they can be used. Experience has shown that these melts will cause some depletion of alloying elements in "K" Monel and Inconel. A serious loss of aluminum

can be expected when submerged-arc welding "K" Monel, and a less serious but important reduction of chromium will occur in Inconel welds.

Special nickel and high-nickel alloy wires are available for use with this process and must be used if suitable results are to be obtained. It is mandatory that clean melt be used. Melt that has been used on nickel or high-nickel alloys is satisfactory for reuse but melt which has been previously used on steel or stainless steel must not be used on high-nickel alloys. Low-quality joints result from the use of scrap melt.

Pending the completion of present research programs, questions on the use of this process with the high-nickel alloys should be referred to the manufacturer of the base materials.

ATOMIC-HYDROGEN WELDING

The atomic-hydrogen welding process, in special cases, is useful for the joining of light-gage nickel and high-nickel alloys. The process has been used extensively for the production of welds where no flux could be used and a dense weld was required. It was and still is one of the few welding processes capable of producing welds that satisfy the requirements of testing by the mass spectrometer. The method has been used for tack welding of light-gage components and the automatic welding of Inconel tubing for resistance heating elements.

OVERLAYING

Nickel, Monel and Inconel can be overlaid directly on wrought or cast steel and excellent results obtained. Prior to the advent of recently developed electrodes, it was necessary to apply a barrier layer of nickel weld metal between the steel and the Monel overlay. Also, Monel-clad steel no longer requires a seal bead of nickel before applying a Monel weld to the clad side. When a thin overlay of Inconel is to be applied, and the job requirements specify the maintenance of a normal Inconel composition, an 80–20 nickel-chromium electrode should be used. The normal dilution by iron from the base plate will result in the required composition.

Figure 10 shows several types of bead contours possible to obtain with the high-nickel alloy electrodes. Contour *A*, which is the type desired for butt joints in any material, has minimum reinforcement and nicely feathered edges. This contour, while suitable for butt joints, is not recommended for overlaying. Contours such as *B* and *C* are more desirable. The reinforcement is heavier and the weld edge makes an abrupt rather than gradual meeting with the base plate. Contours *B* and *C* are recommended over Contour *A* as Contour *A* provides an area at the weld edge that is likely to be in a higher diluted condition and result in hot-short cracks. The dilution at the edges of contours *B* and *C* is much less and adequate material is available for strengthening the hot metal while cooling through any hot-short range. Faster build-up of overlays and reduction of labor and man-hours will result from the use of the recommended bead contour.

Fig. 10 Bead contour for overlays

Fabrication for High-Temperature Service

There is still a considerable amount of information to be developed on the fabrication of muffles and other equipment for uses at temperatures up to 2100° F., but in the work that has been done to date, three basic rules have evolved which are applicable to all high-temperature fabrication. The rules and explanations of their use are shown in Fig. 11. The first rule is: the weld must be all the way through or all the way around. Wherever possible, as in butt joints, in heavy sheet or plate, the joints should be prepared so that the weld penetration can be complete. Items, such as annealing baskets, made up of round, flat or square stock require that the welds be all the way around. That is, where two members abutt or cross, the weld must make a closed joint to prevent the formation of carbon between the contacting members. This carbon accumulation can create sufficient pressure to cause failure at elevated temperatures.

Beveling the butting ends of square or round stock will be required in many instances. Where this is required, the bevel should be to a chisel point rather than

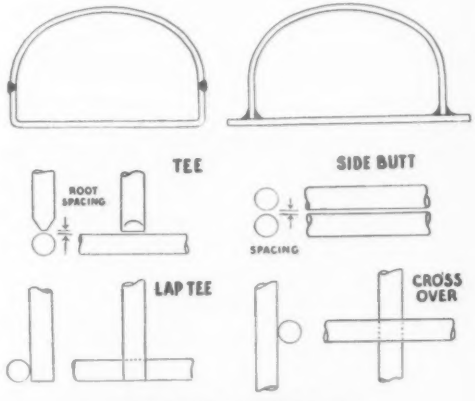

Fig. 11 High-temperature fabrication

to a rounded point. A chisel edge allows better control of heat input and weld contour.

The second rule applies to joint location. Corner joints must be avoided wherever possible. There are very few places where corner joints cannot be avoided, even though this might require redesign in some cases. If a corner joint cannot be avoided make sure the weld is completely penetrated and reinforced. Wherever possible apply a fillet to the inside of the angle.

The third, but by no means the least of these rules is: all welding flux must be removed. Welding flux on nickel and high-nickel alloys will cause corrosion or damage to the base material if the unit is used at service temperatures above the remelt temperature of the welding slag. Figures 12 and 13 are illustrative of the effects that might be expected. This temperature varies rather widely with differences in flux composition. The rules outlined apply to other heat-resisting alloys and stainless steels as well as to nickel and high-nickel alloys.

Certain types of units intended for high-temperature service will give better service life if a sufficient number of loosely riveted joints are used to provide some flexibility. This type of construction is particularly useful for annealing crates or fixtures. Welding is very useful for fabrication of the frames and riveting for joining of support members or bottoms.

Thermal Cutting

Nickel and the high-nickel alloys cannot be cut with the conventional oxyacetylene equipment. This is due, primarily, to the high resistance of nickel to oxidation. However, there are two thermal cutting processes now available which will produce satisfactory results. One of these processes employs an attachment for the conventional cutting torch through which a finely divided iron powder is injected into the cutting-oxygen stream. This iron powder oxidizes and produces an extremely hot stream which is capable of cutting these materials with reasonably good results. The other process employs a hollow arc-welding electrode through which the cutting oxygen flows. A special electrode holder is used that permits the arc to be struck before the oxygen is turned on. The iron in the electrode serves the same function as the iron powder in the process described above. The process is entirely manual and the quality of cut obtained depends upon the operator's skill.

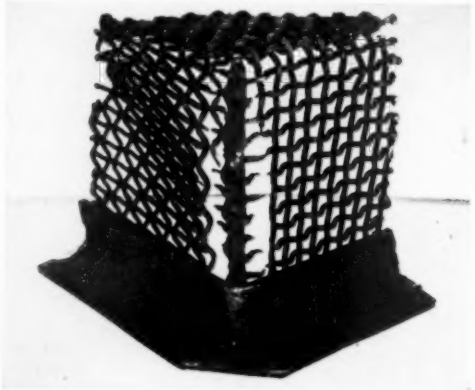

Fig. 12 Corrosion of Inconel by oxyacetylene flux

When using either of these processes, it is essential that the base metal be clean and free of sulphur and lead containing materials prior to cutting.

A third cutting process using flux instead of the iron powder is highly satisfactory for cutting stainless steels and other alloys containing less than approximately 30% nickel.

All burned material or slag should be removed by grinding or machining before welding on the cut edges. Particular attention must be given the age-hardenable alloys in these applications where the cut edge will not be welded but must respond to aging. It is necessary to grind or machine at least $^1/_8$ in. from the cut edge.

Linings

Linings of nickel and high-nickel alloy sheet or strip have been used for a number of years in many types of services, with very good results.

Field lining of existing steel vessels can be done readily if certain precautions are observed in providing proper fit-up, welding skill, inspection and testing. While a lining job cannot be accomplished in the field as cheaply as in the fabricating shop, nevertheless, field lining can be done satisfactorily and economically by various methods.

Fig. 13 Molten flux attack on $^1/_4$-in. Inconel arc-welded pipe. Lower end exposed to 2100° F., upper end cool

Before applying a nickel, Monel or Inconel lining to an existing steel vessel it is necessary that the interior surface of the vessel be thoroughly cleaned. This is accomplished best by sand or steel grit blasting. Any "coke," oxide, aluminum, oil, grease or other foreign matter left on the surface to be lined will cause trouble during the lining operation. It is definitely uneconomical to attempt the lining of a vessel which has not been properly prepared for welding. Some vessels

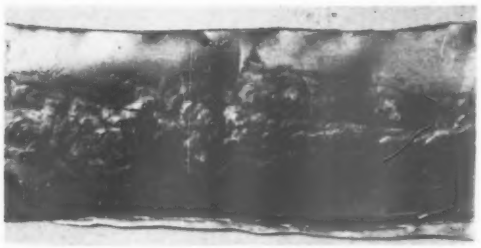

Figure 14

cannot be economically prepared for direct relining with nickel or a high-nickel alloy. This is particularly true of vessels previously lined with lead. Lead that has worked into the vessel surface cannot be completely removed by sandblasting or grinding. When this condition is present a special lining procedure must be followed. The vessel should be sand- or gritblasted after the old lining is removed and the surface laid out to indicate where each joint in the new lining will be located. Steel strips $^1/_8$ to $^3/_{16}$ in. thick by 3 or 4 in. wide should then be welded over these areas. The lining strips or sheets are then welded to the steel strips and thereby avoiding welding contact with the vessel surface. Figure 14 is an excellent example of what happens to the nickel alloys when welded to a lead-impregnated surface. This was one of the early jobs on which the steel strips eliminated the trouble.

When lining heads or domes in vessels, either the strip method may be used or the lining sections cut, formed and shaped into "orange peel" sections to fit the contours snugly.

The thickness of liners has varied from 0.050 to $^3/_{16}$ in.; it is recommended that field linings be not less than 0.062 in. thick for floors and walls, where no overhead welding is required; 0.078 in. thick should be used for overhead work. These minimum thickness values are chosen because thinner liners require a very high degree of welding skill, as well as precision fitting.

The most commonly used method is strip lining using strips up to 18 in. wide but usually 3 to 6 in., and as long as can be conveniently handled. Close center-to-center or rigid attachment of the high-nickel alloys to mild-steel vessels, to eliminate excessive warpage or buckling, is unnecessary since the coefficients of thermal expansion of nickel, Monel and Inconel are very close to that of mild steel; consequently, strips 12 to 18 in. in width can be used in many cases. When vacuum must be considered, strips as narrow as 4 in. may be required.

Plug welding has enjoyed some favor in years past, but has decreased in use. While plug welds do permit the use of wider strips they also provide many more opportunities for leaks to develop. We believe plug welds should be avoided wherever possible.

The diameter of the welding electrode to be used will depend upon the lining thickness in accordance with Table 3.

Table 3—Lining Thickness vs. Electrode Diameter

Lining thickness, in.	*Electrode diameter, in.*	*Amperes*		
		Monel	*Nickel*	*Inconel*
0.062–0.125	$^1/_8$	60–90	85–110	85–105
0.156–0.187	$^5/_{32}$	90–150	105–150	110–130

It is important that the amount of heat input be held to a minimum consistent with good arcing characteristics. Welding speeds and heats must be controlled so as to provide minimum but adequate penetration of the weld metal into the steel shell.

The attachment of the individual strips or sheets can be done following several procedures. Four joint designs or procedures are shown in Fig. 15. Procedure A or lap joints should be used where installation time is a factor or if the vessel surface or contour is irregular.

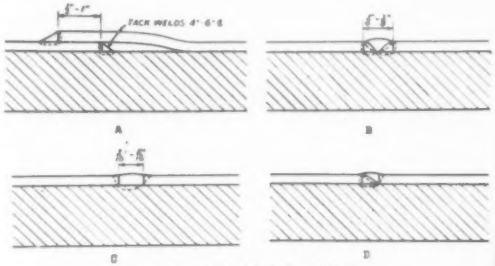

Fig. 15 Applied lining joints

Procedures B and C are used but we do not recommend them. The opportunity for excessive dilution is great, the joints are rather difficult to fit up and require welding skill of the highest order, particularly, in the normally encountered horizontal and vertical positions. Procedure "D" is highly recommended for use where a smooth lining job is desired. Lining composition is easy to maintain in the welds as a minimum of dilution by base metal takes place. Briefly, this procedure involves locating the first sheet or strip, tack welding and then completely welding to the vessel. Restrike bumps are removed by chipping or grinding, the next sheet fitted tightly to the first one, tacking completed and the cover weld made.

Adequate visual inspection and pressure testing carefully carried out will insure tight linings. The only recorded failures of applied linings can be traced directly to inadequate testing and inspection. In each case, the linings were not tight and processing chemicals, particularly those containing sulphur, had penetrated between the shell and lining. Attempts to repair weld were failures as the repair weld and adjacent areas where embrittled by pickup of sulphur. Whenever possible, the lining sections should be sealed from the adjoining sections. This makes possible the removal and replacement of individual sections.

Silver Brazing

Silver brazing may be used to join all nickel and high-nickel alloys to themselves and to many other metals

and alloys whose melting points are sufficiently high. Cleanliness of the parts prior to brazing is imperative.

It is very important to obtain uniform heating of the joint, particularly if the material has been cold-worked. The use of jigs or fixtures to hold the parts in place may, if differential expansion is present, result in applied stress and subsequent cracking of the parts. Most of the commercially available silver-brazing alloys and fluxes are satisfactory for use on the high-nickel alloys but phosphorus-containing alloys must be avoided. Phosphorus, like lead and sulphur, has an embrittling effect. Standard silver brazing fluxes are suitable for the nickel alloys, excepting those of the age-hardening types. All the age-hardenable, high-nickel alloys contain one or more of the three elements—chromium, aluminum and titanium—and their oxides are difficult to remove. Special fluxes are available for these alloys from the regular source for silver-brazing alloys.

Heating for brazing may be accomplished by any of the conventional means such as air-gas or oxy-fuel torches, resistance, induction, salt baths or furnaces with controlled atmospheres.

If difficulty is encountered in the brazing operation it can usually be traced to either lack of cleanliness, high stress, overheating, improper fit of the parts or formation of oxide on the metal before brazing is complete. This is usually due to insufficient flux or, in the case of furnace brazing, an atmosphere with an inadequately low dew point. Figure 16 is an interesting example of silver brazing on a high-nickel alloy.

Copper Brazing

Because of their high melting point, the high-nickel alloys are the only commercial nonferrous alloys which can be copper brazed.

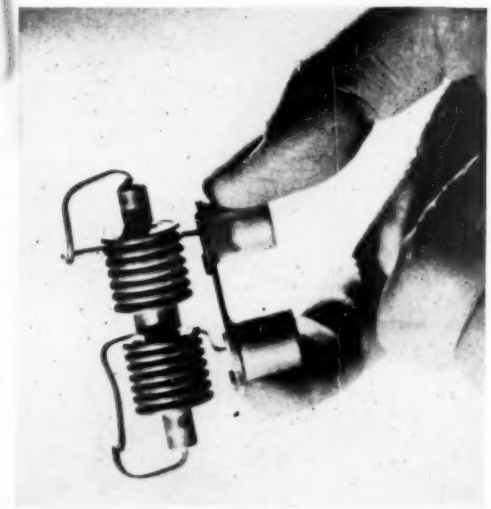

Fig. 16 Assembly of Inconel bellows for fuel pressure gage. Thirty silver-brazed joints must withstand 750-psi. test pressure

Standard designs for copper brazing of steel are used, but more copper is needed since it will not flow as far on nickel alloys as it will on steel. This diffusion is more marked if the parts are at temperature for long periods of time. The copper should be placed in or adjacent to the joint in a manner that does not require it to flow long distances.

Copper plating of the brazing areas, where possible, is a useful means for replacing copper in the joints. Figure 17 is a good example of this use in the fabrication of tubing.

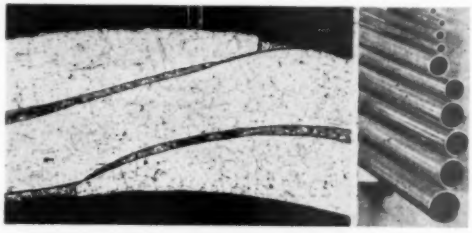

Fig. 17 (Left) Section of typical tube at lap. (Right) Monel bundyweld tubing fabricated by copper brazing

Nickel plating of K Monel and Inconel, particularly when the furnace atmosphere may be slightly impure or wet, will provide protection against the formation of oxides that would prevent a good braze. Another advantage is gained through improved resistance to oxidation and strength by the nickel alloying with the copper.

Light press fits are recommended and parts should be designed to be self locating. The use of jigs or fixtures to hold the parts in place has its disadvantage in the form of uneven heating and inefficient use of furnace time through the added time required to heat heavy fixtures.

Dry dissociated ammonia, dry hydrogen or dried cracked city gas may be used to provide a suitable brazing atmosphere. A dew point of -20 to $-50°$ F. should be maintained on these prepared atmospheres in order to eliminate moisture in the furnace. If cracked manufactured gas is used, the total sulphur must be low—of the order of 15 grains per 100 cu. ft. When the sulphur content is suspected to be marginal, sufficient pilot tests should be made before charging the furnace with a load of completed parts. Sulphur removal towers are commonly used to lower the sulphur content to a safe level.

Brazing for High-Temperature Service

The brazing of high-nickel alloys for elevated temperature service is done following the practices normally used for copper brazing. The brazing operation should be completed before any required age-hardening. Many alloys have been used as brazing materials with encouraging results. Some of these are: the Hastelloys, the

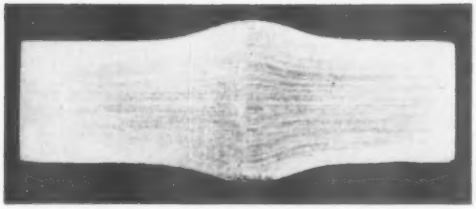

Fig. 18 Cross section of pressure welding in 1 in. diameter. Monel bar macro etched to show flow lines

Colmonoys, 85 silver–15 manganese alloy and nickel-manganese alloys. Some gold and platinum alloys are under investigation and have shown some promise.

Pressure or Solid-Phase Welding

This process may be applied to nickel and high-nickel alloys to produce butt welds in bar, rod and pipe forms (Fig. 18). A finely machined surface is required on the areas to be joined. Cleanliness, adequate pressure and proper heating in addition to properly prepared surfaces are essential to obtain high-quality results.

Resistance Welding

Nickel and the high-nickel alloys can be welded readily by all of the resistance methods. Details of the operations and factors controlling weld quality are given elsewhere.[3] It is not possible to adequately cover this subject in a brief paragraph. An age-hardenable, high-nickel alloy (Inconel X) is being flash welded commercially in sectional areas up to 5 sq. in. to form rings up to 50 in. in diameter.

Dissimilar Joints

Nickel and the high-nickel alloys can be joined readily to stainless steels, mild steel, copper-base alloys, cast iron and many of the so-called super alloys. The results of an extensive investigation on the subject at the Research Laboratory of the International Nickel Co., Inc., will be published soon. In most cases, one of the three basic electrodes—nickel, Monel or Inconel—is used. Joining of these alloys to cast iron is best done by using one of the nickel cored electrodes developed for the metal-arc welding of cast iron.

SUMMARY

There is no mystery connected with the joining of nickel and high-nickel alloys. They are high-quality materials, used principally in corrosion- and heat-resisting applications where their special characteristics present definite advantages over other metals and alloys, and they require a comparable quality of workmanship. Careful attention to the selection of the joining process, cleanliness, preparation of joints, fit-up and testing procedures will avoid trouble and insure the results expected and demanded by industry.

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Swiss Specification for Gas Welding Rods

SUBCOMMITTEE UK4 of Technical Committee TK20 on Welding of the Swiss Society of Machinery Manufacturers submits this tentative specification (No. 140/404) for public discussion, according to the Chairman of the Subcommittee, H. Zschokke. This specification defines the technical requirements for gas welding rods, and is issued at the urgent request of makers and consumers alike. The specification is closely allied to VSM 14043 "Electrodes for Arc Welding" issued in 1942 by the same subcommittee. In view of the fact that the values for strength and ductility for classes GV3 and GA1-GA4 must still be verified by practical experience, it was decided to publish this specification as tentative.

Abstract of "Projet de normes de la Société suisse des Constructeurs de Machines (VSM) pour baguettes de soudure autogene," published in *Jour. Soudure*, **39**, 59–62 (April 1949). Translated by Dr. G. E. Claussen, Chief Metallurgist, Reid-Avery Co., Dundalk, Baltimore, Md.

A. Purpose and Field of Application of the Specification

This specification is intended to govern the classification and purchase of rods for manual gas welding of unalloyed steel conforming to specifications VSM 10611–10661 and 14042. For other welding processes, such as automatic welding, the specification applies only if the same rods are used as for manual welding. The speci-

fication applies to straightened and cut rods, but may be considered to apply as well to wire in coils.

B. Dimensions

Table 1 shows the diameters and lengths of filler rods.

Table 1—Dimensions of Gas Welding Rods

—Diameter— In.	Mm.	Tolerance in diameter, mm.	—Length— In.	Mm.	Volume, cu. mm./m.	Weight, kg./m.
0.039	1	0–0.06	19.7	500	780	0.006
0.059	1.5	0–0.06	19.7	500	1,760	0.014
0.079	2	0–0.06	39.4	1000	3,140	0.025
0.099	2.5	0–0.06	39.4	1000	4,900	0.038
0.128	3	0–0.075	39.4	1000	7,100	0.055
0.158	4	0–0.075	39.4	1000	12,550	0.099
0.197	5	0–0.075	39.4	1000	19,600	0.154
0.236	6	0–0.075	39.4	1000	28,100	0.222
0.315	8	0–0.09	39.4	1000	50,200	0.395
0.394	10	0–0.09	39.4	1000	78,500	0.617

C. Appearance

The drawn rods for hand welding are not annealed and have a light coating of grease or oil. They should be straight to the eye.

D. Marking and Packing

The type of rod (see Section E) is rolled or stamped at regular intervals on joint welding rods (GV series). Instead of stamping, the surfacing rods (GA series) may have the type color, Table 2, painted on one end.

The following information should be on each package:

(*a*) Name of manufacturer and lot number
(*b*) Rod diameter in millimeters
(*c*) Weight of each package and approximate number of rods therein
(*d*) Instructions for correct torch adjustment.

Example of Designation

A GV2-rod, 4-mm. diameter, is designated thus: Welding Rod GV2/4 VSM.

E. Classification and Requirements

Table 2 lists the requirements of the rods using a short torch annealing (extended right-hand welding). Welds made with these rods on steels of good weldability must be free from cracks; that is, no hot cracks due to shrinkage stresses shall appear.

Table 2—Properties of All-Weld-Metal in Horizontal Position

Type	Color	Minimum yield point, psi.	Minimum tensile strength, psi.	Elongation in 5 diameters, % min.	Notch impact value, mkg./sq. mm., min.	Brinell hardness, min.
GV1	Red	25,600	54,000	18	5	110
GV2	White	34,100	52,600	20	8	125
GV3	Blue	39,800	74,000	20	15	150
GA1	Yellow	For surfacing plain carbon steel				200
GA2	Green	For surfacing plain carbon steel				300
GA3	Brown	For wear-resistant surfaces				400
GA4	Black	For surfacing Hadfield manganese steel				190

F. Methods of Testing

1. For Joint Welding Rods (Types GV1 to GV3):

(*a*) One tensile specimen (see VSM 14054, Section D1)

(*b*) Two notch impact specimens (see VSM 14154, Section D2)

(*c*) Chemical Analysis (see VSM 14054, Section D3). Analyses are not generally required.

(*d*) Crack test (see VSM 14052, Section B3). The weld is bent a little and examined with a lupe for cracks.

2. For Surfacing Rods (Types GA1 to GA4):

(*a*) Hardness (see VSM 14053, Section C2). In five readings the hardness must not fall 10% below the required level in more than two readings.

(*b*) Adhesion. A layer of weld metal 0.20 to 0.32 in. thick is deposited over an area 1 x 3 in. on a plate $^5/_8$ to 1 in. thick in four overlapping beads without interruption. The plate shall be at room temperature before welding is begun. The edge of a sharp chisel is forced 2 mm. (0.08 in.) under the surface of the specimen. The deposit shall not peel away from the plate nor must the separate beads peel away from each other.

3. Inspection. At the request of the purchaser, the manufacturer must subject his product to the appropriate tests at a neutral testing laboratory, for example, the Federal Testing Materials Laboratory or the Swiss Acetylene Society.

Power Supply for Arc and Resistance Welding

Load conditions of arc- and resistance-welding plant on public supply mains as prevailing in Great Britain

FOREWORD

THE purpose of this memorandum is to provide supply engineers and welding plant users with a brief statement concerning the types and characteristics of arc- and resistance-welding plant, the load these two types of equipment impose on supply mains and also to give suggestions for methods of assessing the demand.

The memorandum has been divided into two parts: (1) arc-welding plant and (2) resistance-welding machines, since the characteristics of the load from these two types of equipment are entirely different.

Some difficulties have been experienced in the connection of welding plant to supply mains which have hindered development in the use of the electric-welding processes for production work, and in some cases are discouraging consumers from installing welding plant.

It may be mentioned here that the supply undertakings' associations collaborating in the preparation of this memorandum are unanimous in deprecating the 3-phase to single-phase transformer as a possible means of improving welding load characteristics in place of the more generally used single-phase welding transformer connected across two phases of the 3-phase supply. This subject is dealt with more fully in the Appendix.

The British Electrical and Allied Industries Research Association is undertaking tests on welding loads, and a subcommittee of the British Electrical Development Association has under consideration the general question of tariffs for welding supplies.

Part One

ARC-WELDING PLANT

In this section reference is made to the types of plant available, and to the characteristics of the arc-welding load; and methods are suggested by which supply undertakings might assess the welding demand.

This memorandum was prepared by the Welding Sections of The British Electrical and Allied Manufacturers' Assn., in collaboration with Conference of Joint Electricity Authorities and Joint Boards, Incorporated Association of Electric Power Companies, Incorporated Municipal Electrical Association, London Electricity Supply Association, and Provincial Electric Supply Association, before April 1, 1948. Assent to its publication has been given by The British Electricity Authority, 36 Kingsway, W.C. 2, London, England.

It must be emphasized that the load imposed on supply mains by arc-welding plant is entirely different from that of resistance-welding machines, details of which are given in Part Two and it is recommended that supply undertakings should view these as two separate types of equipment, having different load characteristics and justifying different methods of payment for the power consumed.

1. Characteristics of the Arc-Welding Load

Arc-welding plant consists of either motor generators, transformers or rectifiers. The transformers are either of the single-phase single-operator or 3-phase multioperator types. Unlike resistance-welding machines, the arc-welding plant draws a comparatively steady load from the mains for a period between one and two minutes, and the ratio of welding time to connected time may be as high as 75%, although usually about 30%. Even at the instant of short circuit, the kva. from the line is no more than about 15% above that taken while welding is in progress. The supply characteristic imposed by arc-welding plant is comparable with those of intermittently rated motors, such as those used for lifts or cranes.

It is of importance to bear in mind the above distinction between power requirements for arc-welding plant as compared with those for resistance-welding machines.

2. Motor-Generator Arc-Welding Plant

This type of plant consists of standard motors driving drooping-characteristic or constant-potential generators to supply one or a number of operators. Where alternating-current motors are used they provide a balanced 3-phase load with a reasonable power factor, and do not present any difficulty to supply authorities except that arrangements must be made for lines to carry the load in the same way that capacity is required for any other motor-driven load.

3. Transformer Arc-Welding Plant

It is desirable that users of welding processes, where they have a predilection for transformer arc-welding

plant, should not be deterred by Supply Authorities from installing single-phase transformers where they are suitable for the work to be done and where supply conditions permit. In this connection attention is drawn to the Appendix. Refusal to connect alternating-current plant may have a detrimental effect upon the development of welding as a manufacturing process.

There are two main types of welding transformers: (*a*) three-phase multioperator transformers and (*b*) single-phase single-operator transformers.

These types of plant are described as follows:

(*a*) *Three-phase multioperator transformers* supply welding arcs through welding regulators usually designed in accordance with B.S. 1071-1943. The transformers are connected delta-interstar and a reasonable diversity of load is obtained on the primary side.

This type of equipment is generally made in the sizes shown in the following table, providing a maximum of 300 amp. to each of 3, 6, 9 or 12 operators.

Type	*Maximum kva rating*	*Continuous kva rating*	*Average power factor*	*Primary current at 400-v., 3-phase, 50 cycles at continuous kva. rating, amp.*
300/3	90	54	0.35	78
300/6	180	90	0.35	130
300/9	270	122	0.35	176
300/12	360	153	0.35	221

The figures given above are without power-factor correction. B.S. 1071-1943 recommends standard sizes of capacitors to improve the power factor on the primary side, and the figures in the following table show the result of the application of these capacitors.

Type	*Continuous kva. rating*	*Capacitor size kva. at 400 v.*	*Combined continuous kva. rating*	*Corresponding power factor on primary side*	*Corresponding primary current at 400 v., amp.*
300/3	54	16.5	39	0.48	56
300/6	90	30	63	0.5	91
300/9	122	45	82	0.525	118
300/12	153	60	99	0.54	146

Much higher power factors are experienced in service (since diversity factors are usually lower than those assumed in B.S. 1071-1943) and the following are nearer the average:

Type	*Corrected power factor*
300/3	0.63
300/6	0.67
300/9	0.75
300/12	0.78

It should be noted that there will be periods when little or no welding is carried out although the capacitor is connected permanently to the supply; the capacitor will then serve the purpose either of improving the total power factor of the works load or of the general supply to which it is connected.

The above figures are based on the continuous kva. rating, thus the plant has a British Standard Thermal Rating for both the transformers and the welding regulators. The maximum kva. which is given for the various sizes is that which can be drawn from the supply mains if the total number of operators is working simultaneously at the maximum welding current of each regulator. This rarely, if ever, happens in practice, but the momentary overloads which are possible in these circumstances can be regarded as normal to any power transformer. It is emphasized that the only rating to be considered is the continuous British Standard Kva. Rating, as this is the normal rating of the plant to give standard temperature rise when tested in oil at the manufacturer's works.

The anticipated power factors given in the last table above are based on a load equivalent to approximately 60% of the maximum kva. welding rating, and experience shows that these can be accepted as reasonable figures.

(*b*) *Single-Phase Single-Operator Transformers.* The majority of single-operator arc-welding transformer plants is of the straight single-phase type suitable for connection across two phases of a 380/440-v. supply system. This is the simplest type of welding transformer to install in which power factor can be corrected easily. The various sizes have been standardized by manufacturers, and are generally as follows:

Maximum continuous hand-welding current to B.S. 638-1941 amps.
150
200
300
400
500
600

These are the maximum continuous hand-welding currents, but the thermal rating of the plant is based on the continuous kva. rating which in turn is based on the maximum practical load factor on the plant.

The secondary voltage of the transformer, which feeds the welding regulator on these units, will vary according to manufacturers' standards; the range is approximately 75 to 100 v. at no-load.

The average power factor for single-operator welding transformers when using normal coated electrodes is 0.35 lagging. Static capacitors can be connected on the primary side of the transformer to improve the supply power factor. The optimum size of the capacitor would improve the power-factor to approximately 0.6 lagging at the continuous kva. rating. This results in equalizing the kva. drawn at no-load with that drawn at the maximum kva. rating.

Suggested sizes of single-phase capacitors for 400 v., 50 cycles, are as follows:

Continuous kva. rating	*Line current, A*	*Average power factor*	*Recommended size, kva.*	*Corrected line power factor lagging*	*Combined continuous kva. rating*	*Corrected primary line current, A.*
9	22.5	0.35	4	0.58	5.4	13.5
12	30	0.35	6	0.625	6.9	17
18	45	0.35	8	0.6	10.4	26
24	60	0.35	12	0.625	13.7	34
30	75	0.35	15	0.625	17.1	43
36	90	0.35	18	0.625	20.5	51

4. Method of Assessing the Welding Demand

From the foregoing it would appear possible to assess the welding demand to give adequate compensation to supply undertakings without imposing undue penalties on consumers and restricting development in the use of the electric arc-welding process. It is suggested, for instance, that although, in some cases, the load factor of an arc-welding installation may be low, in many cases it is high enough to justify applying normal power tariff considerations.

Part Two

RESISTANCE-WELDING MACHINES

A brief description is given below of the types and characteristics of resistance-welding machines and suggestions are also included for methods of assessing the power demand.

1. Types of Resistance-Welding Machines

The various types of resistance-welding machines are those for spot, projection, butt and flash butt and seam welding, and also machines for heating rivets, bars, etc. Generally all these machines are characterized by the following features:

(*a*) The load is of an intermittent nature; the duty cycle (i.e., the ratio of welding time in cycles per hour to the total number of cycles per hour) varies from 2 to 20%; seam welders and heating machines often have a higher duty cycle.

(*b*) The momentary current taken from the mains is often appreciably greater than that corresponding to the continuously rated load of the machine, because in most cases the welding current flows for a short interval of time in each duty cycle.

(*c*) The load, except for certain limited nonferrous applications, requires a supply of single-phase alternating current; if the supply is 3-phase it is customary to obtain this by connecting across 2-phase lines of the supply in order to reduce the current demand from the line.

(*d*) The power factor is often low but may vary between 0.2 and 0.8, thus the current taken would be higher than with a unity power-factor load. Corrective equipment may be utilized.

(*e*) Owing to the low-duty cycles, and because of their transient nature, the maximum peaks are not shown on normal kva. maximum demand meters, which generally integrate over a period of 10 minutes or more.

(*f*) The average consumption registered in units is generally very small compared with most other plants with similar loading, except for seam welding and heating machines.

2. Supply Requirements

When considering the installation of resistance welding machines, preliminary discussion between the supply engineer, consumer and welding-machine manufacturer is essential.

The essential requirements to ensure a satisfactory supply to resistance-welding machines are:

(*a*) Adequate transformer mains and supply service capacity to supply the welding load at standard rating.

(*b*) The voltage drop on the mains and the internal wiring should not be so large that flickering of lamps occurs, either at the customer's premises or elsewhere in the neighborhood.

3. Factors to Be Considered with Regard to Supply

The situation described in 2 (*b*) is less likely to occur if any of the following conditions exist:

(*a*) The consumer already has such a large installation that the additional peak demand is of no great consequence.

(*b*) The consumer has his own high-voltage supply.

(*c*) Capacitors are correctly installed for power-factor correction. To ensure this the supply undertaking and machine manufacturer should always be consulted.

(*d*) A group of machines is interlocked so that no two or more can operate at the same instant. This condition applies only in the case of an installation consisting of a very small number of machines as, owing to the high diversity factor with several machines, the simultaneous operation of an appreciable number is improbable.

(*e*) The duration of the current flow is so short that the flicker is not noticeable.

4. Existing Methods of Assessing Demand

It is reasonable that the supply undertaking should be recompensed for the capital charge involved in providing the welding supply, but the existing method of

relying on the maximum-demand indicator is unsatisfactory to supply undertakings. The alternative, now sometimes adopted, of basing a fixed kva. charge on a percentage of the nameplate-welding rating of the machine may be inequitable to the user when based on ratings before standardization of resistance-welding machines was introduced by the manufacturers (see 5), or where diversity factors from B.S. 638-1941 (applying to arc-welding plant) are used, and cases have occurred where this method of assessment has made the cost of resistance welding prohibitive.

5. *Resistance-Welding Machine Ratings*

Manufacturers have agreed on resistance-welding machine ratings which provide a satisfactory basis for assessing demand. In the case of machines manufactured before the standardization of ratings (some of which may not be marked with a rating), the primary current can be measured during the welding operation, and the nominal kva. rating determined. A comparison with the standard nominal rating of similar machines can also be made by reference to the manufacturer.

The following methods of rating were standardized by resistance-welding machine manufacturers on Mar. 1, 1946, to assist users and electricity supply undertakings to assess the capacity of resistance-welding machines, both in relation to the work they are required to do and the demand made upon supply lines.

In addition to the customary data (such as name of manufacturer, serial number, etc.) the minimum information shown on resistance-welding machine nameplates is:

1. Spot- and Seam-Welding Machines

(*a*) The nominal kva., this being 50% of the short-circuit primary kva. on top tapping.
(*b*) Primary voltage.
(*c*) Primary current, this being the short-circuit primary current on top tapping.

Some manufacturers add other information, either on the nameplate or on data sheets supplied with machines, or in instruction booklets.

The secondary current and the minimum duty cycle are always quoted to the user although not necessarily on the nameplate.

2. Projection Welding Machines. The same information is given on nameplates for projection welding as mentioned above for spot- and seam-welding machines, but since there are no short-circuit conditions, between the platens of a projection-welding machine, the short-circuit primary kva. is measured with a solid steel block or section inserted between the platens, of thickness equivalent to the total added thickness of the job for which the machine is designed, and having an area equivalent to the sum of the areas at the bases of the maximum number and size of projections for which the machine is designed.

3. Flash Butt and Butt-Welding Machines. The nameplates of these machines show:

(*a*) The maximum kva. on top tapping when the machine is set up for welding a stated maximum area of steel stock. (No provision is made yet for rating butt and flash-butt welding machines for nonferrous materials.)
(*b*) Primary voltage.

6. *Diversity Factor*

When assessing resistance welding demand, account should be taken of the diversity factor in the operation of a number of resistance welding machines in the same factory. It is recommended that:

(*a*) The largest machine in a factory (or any machine where there are a number of the same nominal kva. rating) should be assessed at 100% of its nominal kva. rating.
(*b*) All other machines should be assessed at 10% of their total nominal kva. ratings.

7. *Conclusion*

By adopting these diversity factors, the supply undertaking will be assured that it is adequately recompensed and that the consumer will have an additional kva. charge to pay for each individual resistance-welding machine installed, although it can be demonstrated that the peak demand in a mixed load is normally determined by the largest machine installed.

Appendix

THREE- TO SINGLE-PHASE AND SINGLE-PHASE WELDING TRANSFORMERS

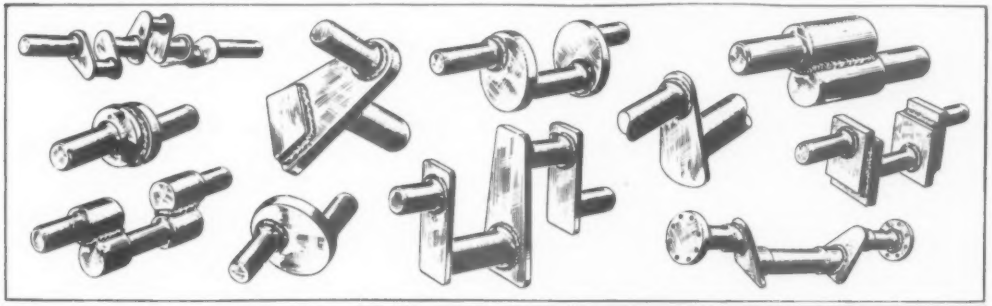
Single-operator type arc-welding transformers have been manufactured for connection from three- to single-phase, and external 3/1 phase transformers have been supplied with resistance-welding machines; but it is stressed that welding plants of this type offer no advantage to supply undertakings, since the welding load in any event is essentially single phase, and the installation of three- to single-phase transformers merely transfers the single-phase load to the primary side where it is split up in the open-delta winding in the ratio of 1/2, 1/2 and 1, but at differing power factors. The kva. required is approximately 15% higher than for a single-phase transformer, and one of the supply lines must carry the current drawn from the other two lines requiring 15% more material on one line. It is also difficult to correct the power factor with this type of transformer.

How to Build Cranks and Crankshafts

Here are some thought starters on welded design furnished through the courtesy of The Lincoln Electric Co., Cleveland, Ohio

STRONGER, more durable machinery parts like cranks and crankshafts are being fabricated from steel at lower cost with arc welding. By using steel plate and standard mill shapes, manufacturers are able to eliminate the expense of patterns or dies otherwise required to produce castings and forgings.

With the greater flexibility of arc welding, manufacturers are also able to fabricate all types of machinery



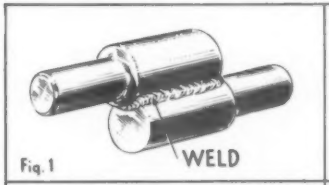


Fig. 1

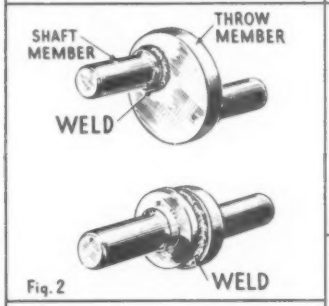


Fig. 2

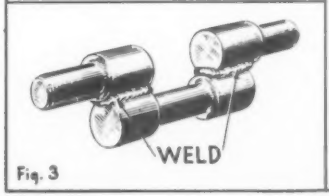


Fig. 3

A variety of cranks and crankshafts fabricated from steel at lower cost with arc welding

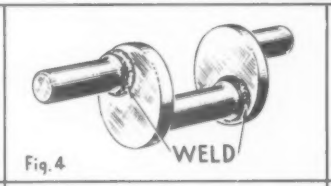


Fig. 4

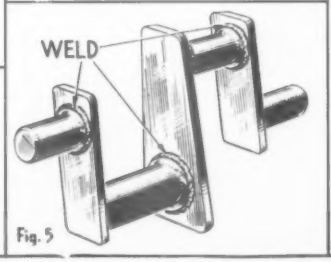


Fig. 5

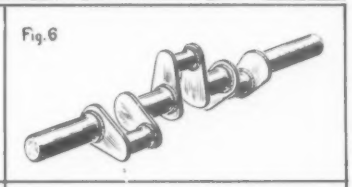


Fig. 6

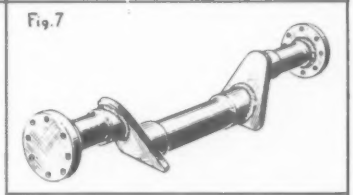


Fig. 7

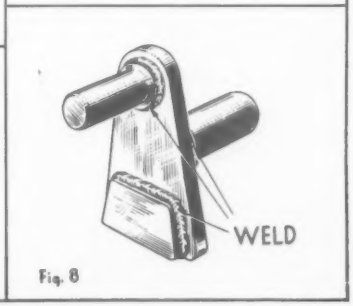


Fig. 8

parts with a minimum of fixture and tooling expense. In many cases, component parts can be premachined on light, fast equipment prior to arc welding, eliminating the need for heavy, more costly turning machinery. A wide variety of steel analysis may be used with heat treatment to produce any practical strength and wear characteristics.

The simplest of crank designs is shown in Fig. 1. Two plain studs are fillet welded longitudinally. If accuracy of throw is relatively unimportant, two round bars having a diameter equal to the throw can be thus weld-assembled. If a longer crank throw is desired, the studs can be fillet welded to a disk (Fig. 2), or two studs positioned back to back for the correct throw and their flanges fillet welded.

The elements of a simple, single-throw crankshaft are shown in Fig. 3. Where the throw of the crank exceeds the diameter of the shaft members, disks cut from bar stock or flame cut from steel plate (Fig. 4) are used. For good appearance or balance, the weld-assembled crankshaft can be mounted between centers and a turning cut taken on the throw members at the same time that finishing cuts are being taken on the shaft members.

Multiple throw crankshafts (Figs. 5 and 6) are likewise fabricated by arc welding to suit all requirements of number and size of throw. The crankshafts can be provided with end-flange plates for power take-off as shown in Fig. 7. These flanged plates are simply fillet welded to the shaft members. In most instances, multiple throw crankshafts are machined all over after welding to attain precision size, alignment and balance.

Counterbalancing of crankshafts becomes a simple matter with arc welding. Counterweights as shown in Fig. 8 can be attached at any point by fillet welding. Small deposits of weld metal can also be added where precision balancing is involved.

Cutting Circles

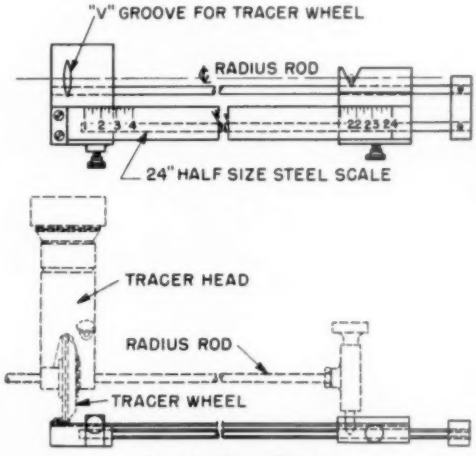
Convenient gage for circular flame cutting on tracer type machines

by J. O. Jordan

THE accompanying sketch shows a time-saving device for use when any amount of circle cutting is done on tracer-type flame-cutting machines. The gage permits quick, accurate setting of the radius rod for the required diameter circle in one simple operation.

The device includes a block with a "V" groove into which the wheel of a tracing head fits, a scale and a movable center block with a notch to receive the point of the radius rod center. The scale is half-size, so that it reads in circle diameter.

In use, the tracing wheel is placed in its groove in the stationary block, and the movable block is set to the desired diameter according to the scale. When the center point is placed in the notch of the movable block and the lockscrew is tightened, the gage is removed and the cutting machine is set for the desired diameter circle or arc.



Gage for Flame Cutting

J. O. Jordan is with the Chicago District of the Air Reduction Sales Co.

Rowboats Used in Unusual Standpipe Dismantling Job

Ingenious combination of gas-cutting torches and boats eliminates the use of expensive scaffolding

ORDINARILY, the best way to make money is not to offer payment for doing welding or cutting jobs. But here's an exception to prove the rule.

A municipal water bureau advertised for bids to remove an obsolete 120-ft. standpipe. The high bid of 14 received was $5500 but the low bidder, allowing for the salvage value of the steel, offered the bureau $906.12 for the job!

Therein lies the story of how two ace marine and structural workers teamed up Airco equipment with rowboats to work from *inside* the standpipe instead of using expensive scaffolding on the outside.

They floated two 10-foot row-boats in the open top riveted structure, rigged a scaffold on the pipe edge and cut out half-ton or heavier sections of the steel plate with the oxyacetylene flame, lowering the pieces to the ground with a winch-truck and cables.

As the sections of the tank were cut away, the water was lowered to put the rowboats and scaffolding on a comfortable working level. About 14 tanks of oxygen and three of acetylene were required for the flame cutting. Since the top plates were about $^{5}/_{16}$ in. in thickness and the lower plates 1 ft. $^{1}/_{16}$ in., the work became progressively slower as the bottom was neared, but the entire job was completed in three weeks.

Tanks of oxygen and acetylene were pulled to the top of the standpipe with the winch-truck's power, which also braked the descent of empty tanks and cutout sections of steel plate. At the top and at graduated working levels, the tanks of gas were cradled in an old oil drum with its top removed, the drum raised and lowered by a rope and pulley arrangement.

In the tank, workers used small boat ladders which hooked over the standpipe's edge, to carry their cutting torches about. Holes were burned through each section, near its upper corners, before its removal. Eye bolts were fastened in these holes and lowering cables attached. The proximity

Data and illustrations courtesy of Air Reduction Sales Co., New York 17, N. Y.

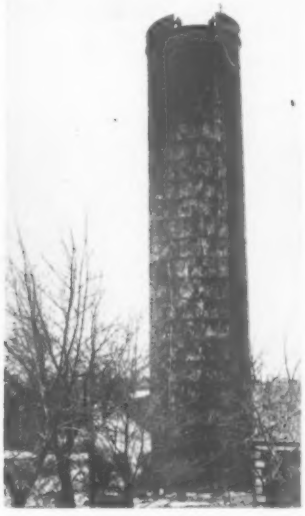


Fig. 1 View of 120-ft. standpipe, with first section of steel plate beginning its descent

Men ascended to top on steel ladder on side of pipe. Buildings at foot of pipe had to be protected, hence lowering of sections as cut

Fig. 2 Torch and oxyacetylene flame is shown as iron salvage worker cuts last holding strip on steel section along top edge of standpipe

Fig. 3 Tanks and controls are visible in old, uncapped oil drum, supported by a rope-and-pulley arrangement: hose for torches is also visible, with man working in rowboat

of an existing high service pump station just at the foot of the standpipe made this careful lowering procedure necessary. As the work neared the ground, smaller sections were cut out and dropped into the lowering water.

Probably this was the first time that cutting torches were used from rowboats so high in the air.

Make This Ladder from Pipe

by L. W. Young

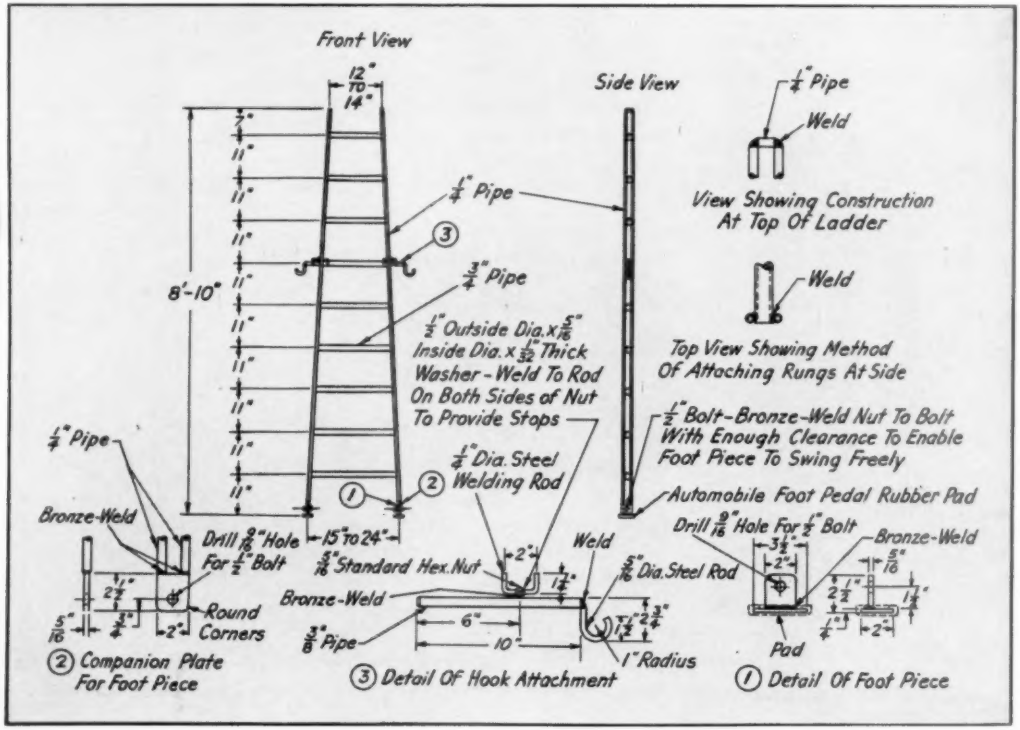
WITH your blowpipe and 1/4- and 3/4-in. pipe you can make this useful lightweight ladder. The ladder is 8 ft. 10 in. long and in normal use it supports a safe load of 500 lb. It easily supports the weight of three workmen, as shown in Fig. 1. The amount of deflection is only about 1/4 in., although the load is concentrated on the unsupported center section.

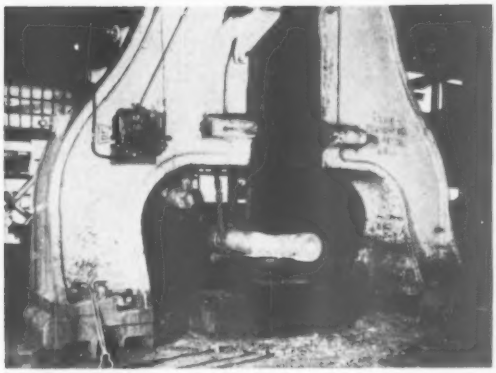
You often find that welding shop customers need equipment of this type in their business. Build up an additional source of income for your shop by making and selling ladders, stools and other items which have been shown recently in this section.

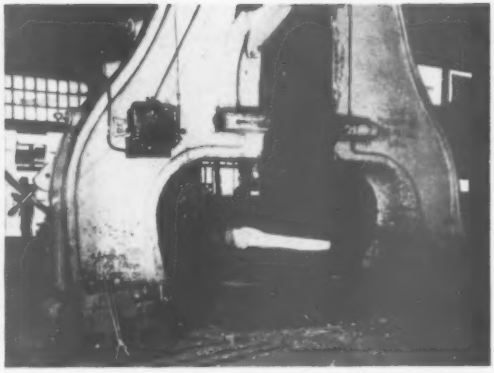
The sketch on this page shows the material you need to build this ladder. The details for attaching the rungs to the sides, and for making the footpiece are also shown. Your welding and cutting blowpipe are the only tools you need.

L. W. Young is Development Engineer, The Linde Air Products Co., Newark, N. J.

Fig. 1 In normal use the ladder will support a safe load of 500 lb. The ladder hardly bends even when three men concentrate their weight on the unsupported center section







Figs. 1 and 2 First step in die-part production is the flattening of the axle into a rough billet

Welding Produces Forming Dies from Scrap Axles

CONVERTING scrapped locomotive axles into large press dies for forming car parts is a worth-while economy for many railroads. This operation is made possible in the Union Pacific Omaha shops by means of forging hammer, flame cutting and automatic submerged welding. In general, the procedure is to flatten the axles, trim them and prepare Veed edges by flame cutting. The next step is to weld a sufficient number of prepared billets together for the particular die being made. Final step is to weld on detailed forming parts for both male and female halves.

Figures 1 and 2 show the scrap axle that has been heated to about 2300° F. being flattened under a drop hammer. Desired thickness is controlled by this operation. After the flattening operation the rough billets go to the flame-cutting department where they are cut to specified size. Billet edges that are to be welded are prepared with the double Vee pictured in Fig. 3. The Unionmelt welding shown calls for $\frac{1}{4}$-in. rod and proceeds at about 14 in. per minute. Using

Data and illustrations courtesy of The Oxweld Railroad Service Co., Unit of Union Carbide & Carbon Corp., Chicago, Ill.

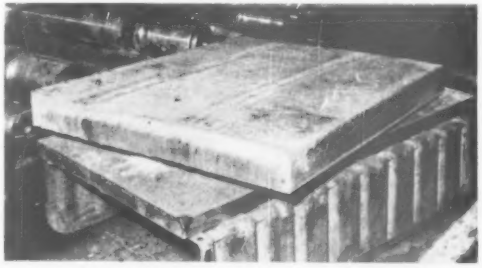


Fig. 4 Two weldments that have been made from scrap locomotive axles

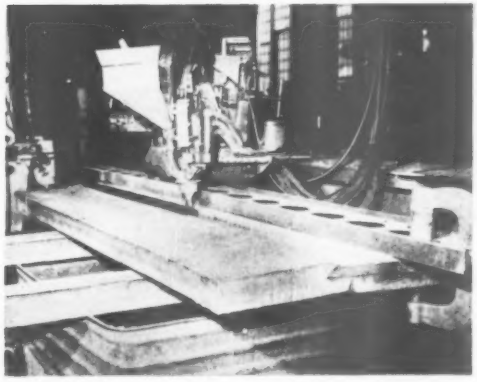


Fig. 3 Unionmelt welding is used to make multiple passes in welding together flame-trimmed billets

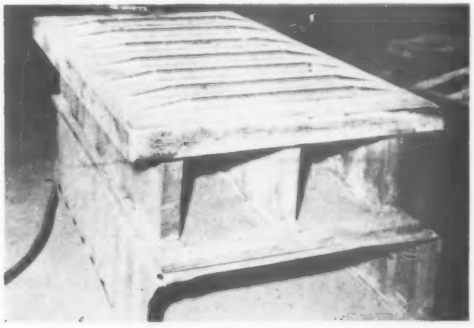


Fig. 5 Male half of car-part forming die that has been made as described in the accompanying report

from 800 to 1100 amp., a. c., the required number of passes are made on each side of this $3^1/_2$-in. thick billet.

Figure 4 shows two semicompleted weldments that are parts of forming dies. The thicker piece on top has been formed from three axles while the thinner slab on the bottom was made from two. Formed weldments of this type have been made up to 100 in. in length, $3^1/_2$ in. thick and 50 in. wide.

A male half of a nearly completed die, the principal parts of which are made from locomotive axles, is seen in Fig. 5. Using the method outlined here, billets have been made from locomotive axles to make dies for corrugated ends for coal cars, corrugated dump doors, car side posts, spring planks, front and back flue sheets and many types of face plates.

Welded Repair of a 52-Ton Cast Steel Press Base

by Leslie C. Haynes and J. F. Sloan

THE Haynes Welding Corp. of Worcester, Mass., received a particularly challenging job recently involving the repair of a 52-ton cast steel base for a 187-ton, three-way drawing press. The intricate repair job was further complicated by the discovery of shrinkage cavities. The procedures and techniques employed in the successful completion of this job are as follows:

The first operation was to cut out the metal of either side of the crack to permit a 100% weld. This operation was then performed on the two outer ribs. The joint, after the burning, was cleaned thoroughly of any foreign matter by air hammers.

The welding of the two outside ribs was started simultaneously until a point was reached at the beginning of the crack of the center rib. During this operation of welding up the sides, each bead was hammered to a shiny finish, thus insuring a job free from locked-up stresses and thermochecks. Trammel points were employed as a means of control to check any expansion or contraction of the base during the welding operation. These points were checked every four hours.

Following this, the metal in the center rib was cut out and cleaned thoroughly. Then all three ribs were welded simultaneously with each bead being hammered. The peening operation is done after each layer of weld is deposited on the surface, not as each rod is deposited. The building-up operation on the three ribs was continued until these sections were built up within 2 in. on the inside of the top plate. Then sections in the top plate over the top of each rib were cut out. This left about one-third of the top plate intact.

At this point, shrinkage cavities of considerable magnitude were encountered. Dimensions of the three cavities were: right rib, 5 x 7 x 6 in. deep; center rib, 7 x 8 x 10 in. deep; left rib, 6 x 6 x 7 in. deep. We then proceeded to build up the sections as a unit, hammering continually to relieve stresses. The welding was carried on until a point 3 in. below the top surface of the top plate was reached. At this point, we completed the cutting operation on the top plate and cleaned thoroughly.

Following this, all the sections were built up to a common level. During this and the preceding welding operations, two types of welding techniques were employed. On the sides, close parallel beads were used in an effort to continuously wash the slag to the front of the weld. The melt was maintained at an angle of approximately 20°. When going from the vertical to the horizontal, we still maintained stringer beads, back-stepping and alternating position of weld. Upon reaching the top plate where the danger of stresses was greatest, we resorted to a technique known as block welding. This method consists of dividing the crack to be welded into equal parts and building up pads of metal approximately 4 in. long to cover the length of the opening. This gave us 12 pads to weld up. Starting from the middle and working out, we took the odd pads on the way out and the even pads on the way in. After the deposit of each pad, it was hammered thoroughly. This procedure was carried on to the conclusion of the job.

Reinforcement strips were next assembled. No welding was done on the ends of these reinforcements because a shearing action would have been set up. A check on the Trammel points showed a movement of approximately 0.0362.

The materials used on this job were Airco 78E Electrodes (E6010), 500 lb.; oxygen and acetylene, 1500 cu. ft. In addition, a No. 10 Radiagraph cutting machine, hand-cutting equipment and air hammers were used.

The drawing press is now back in service and the welded repairs have proved completely satisfactory.

Leslie C. Haynes and **J. F. Sloan** are President and Superintendent, respectively, of the Haynes Welding Corp., Worcester, Mass.

Fig. 1 Preparation for welding in early stages showing extent of shrinkage cavities encountered

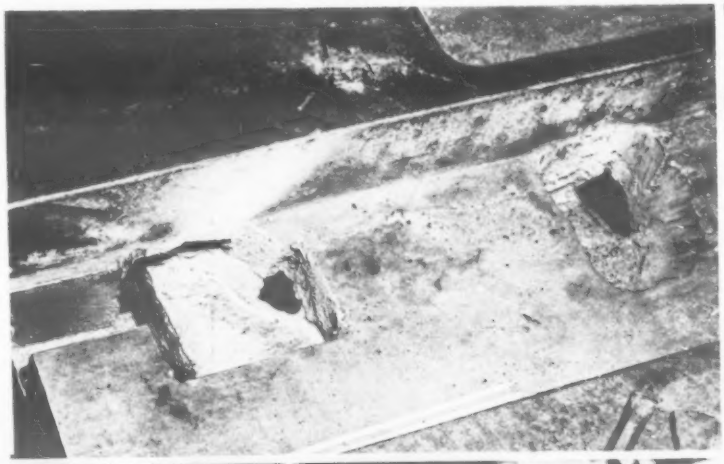
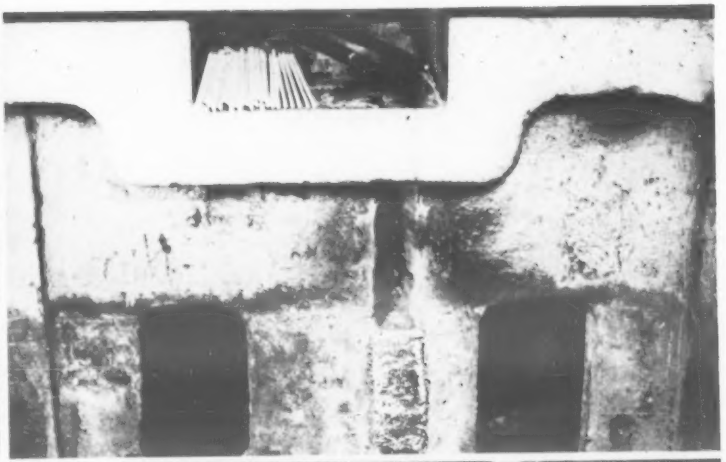


Fig. 2 Welding done on outside ribs



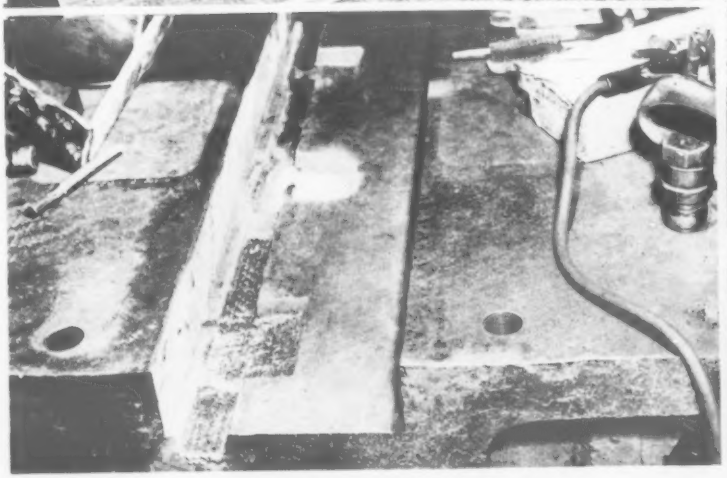


Fig. 3 Welding of top plate partially completed. Also visible is welding to fill in shrinkage cavities

Fig. 4 Completed welding on top plate

Arc-Welded Beam and Column Framing

Studies in structural arc welding provided through the courtesy of The Lincoln Electric Co., Cleveland 1, Ohio

RECENTLY several outstanding buildings of modern all-welded steel frame construction have been designed and built to the satisfaction of both the fabricators and the architects and to the pleasure of those who have accomplished the erection.

Since the details used in these structures are outstanding examples of sound engineering practice, it is the purpose of this article to portray the manner in which some of these heavy beam and column details have been accomplished.

Figure 1 is a sketch in trimetric projection of a typical continuous interior wind bracing girder and column connection that was used for some of the heavier framing details at the third floor level of the new ten-story addition to the *Register* and *Tribune* Building in Des Moines, Iowa. It shows the junction of two 36-in. WF 260-lb. beams with the flanges of a 14-in. WF 426-lb. column and with two 16-in. WF 40-lb. beams framing to the web.

In this design all holes were eliminated from the main columns by fillet and plug welding erection brackets to the web, and erection angles to the column flanges.

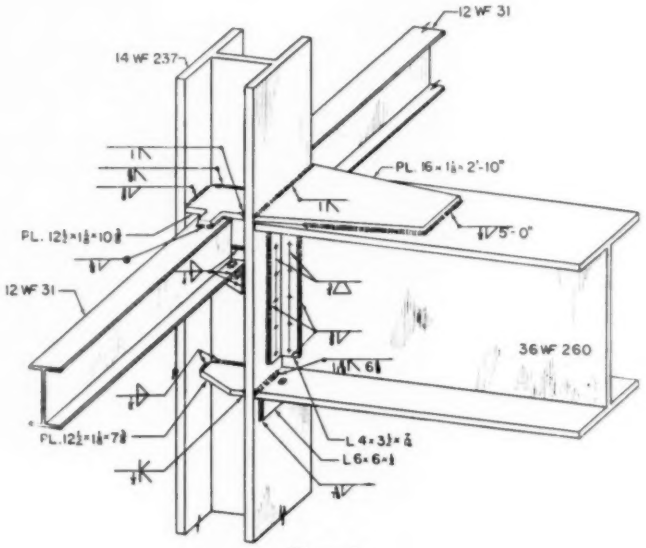


Figure 2

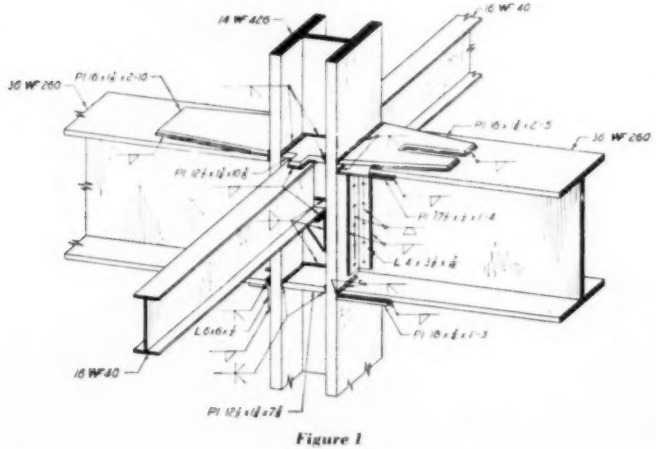


Figure 1

Thus, the handling for punching and drilling is confined to small pieces of angles that are easily handled and can be carried to the columns for welding in the shop. Holes were provided, however, in the ends of the girder webs and in the outstanding legs of these angles for the convenience of using drift pins and bolts for alignment and temporary support during erection.

Full continuity was obtained at the bottom of the 36-in. beams by field butt welding the bottom flanges of the beams to the column flanges to bear opposite a shop-welded stiffener between the column flanges.

At the top of the 36-in. beams the top flange cover plates and the stiffener plates between the column flanges are shipped loose for convenience in erection. Tee-beam erection brackets are provided on the column webs to support the 16-in. WF beams and the plates between the column flanges are field butt welded to the column flanges after the 16-in. beams

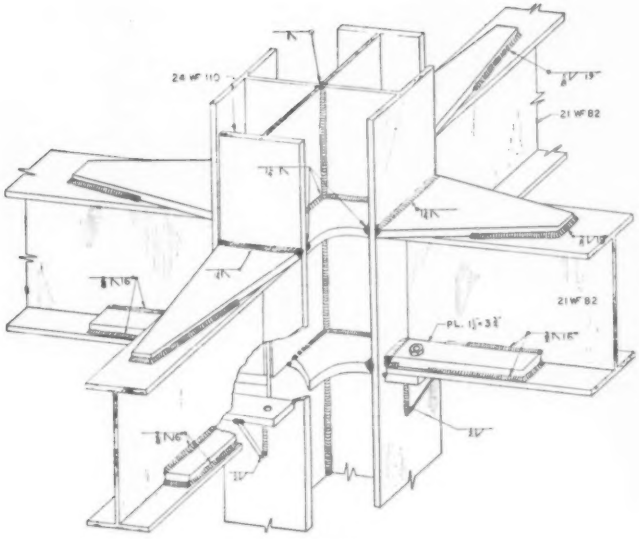


Figure 3

have been field welded to these erection brackets.

The outside cover plates are then butt welded to the outside faces of the column flanges and fillet welded to the top of the 36-in. WF beams to complete the detail.

Figure 2 is a similar sketch of a typical wall column or end column of the same building.

This detail is the same except that only one 36-in. WF 260-lb. beam is supported by the column and the heavy field welds are therefore confined to only one flange of the column. The stiffener plates are field welded to the inside flanges and the web of the column, but are not welded to the outside column flange.

Another ingenious and well-designed detail of this type where equal rigidity was provided in both directions for seismic forces is shown in Fig. 3.

This detail by Holmes and Narver is in the new *Los Angeles Times* Building in Los Angeles.

In this structure, 21 WF 96- and 82-lb. beams in both directions were joined by welding to the flanges of a double 24 WF 110-lb. cross type column.

Shop-welded, $1^1/_4$-in. plates were provided between the column flanges opposite the beam flanges to provide for the full continuity of the stresses and shop-welded tee-shaped bracket beam seats were provided on the flanges with $^7/_8$-in. bolt holes in the bottom flanges to hold the beams during erection. The $1^1/_4$-in. plates were single bevel welded to the inside of the flanges and to the web all around the plates to provide diaphragms and back up plates.

Continuity is provided on the outside face of the column at the top flange by field butt welding $1^1/_4$-in. top cover plates to the outside face of the column and then fillet welding them to the top flanges of the beam.

At the bottom flanges full continuity was provided for in a similar fashion except with two $1^1/_2$- by $3^3/_4$-in. plates fillet welded on top of the bottom flange of each beam on each side of the web.

(To be continued)

Metallizing of Packing Areas

by J. E. Wakefield

DURING the last 20 years, metallizing has been used quite extensively for rebuilding worn packing areas on pump shafts, sleeves, rams, plungers, turbine shafts and other parts. Generally, packing areas are subject to both wear and corrosion. For that reason, better metals are important. With metallizing, it is often possible to rebuild worn surfaces with metals which will stand up better under the conditions than the metal from which the part was originally made.

Take the case of the power plant up in Massachusetts. They had some badly scored bronze pump sleeves from some circulating pumps. Sleeves were 4 in. diameter and about 14 in. long. Scored areas ran around 6 in. The sleeves were cut down to even up the wear and expose clean new metal. Next, a square thread was cut in the surface, 14 to the inch. This was done with a square-nosed tool about 0.045 in. wide, and threads went in 0.020 in. Then, a special type of roughing tool, consisting of five saw-like blades with teeth set staggered, was run over the threads to cut them up still further. The tool also rolled their edges slightly producing dovetails in each groove.

The sleeves were sprayed with a medium-chrome, medium-carbon stainless steel, much as shown in Fig. 1. Sprayed coating was built up about 0.040 in. oversize, then wet ground back to standard. Cost of the entire metallizing operation was less than $8 per sleeve. Compared with the price at the time for new bronze sleeves, $44 each, there was a very real saving from metallizing. Incidentally, at the same time, stainless steel sleeves were priced at $169 each. It is interesting to know that the sprayed stainless steel sleeves outlasted new bronze ones more than 3 to 1.

Packing troubles occur on turbine shafts too. Figure 2 shows the metallizing of a G. E. 2500 K. W. turbine shaft. Four packing sections were badly pitted. In this case, the job was done in place, without complete dismantling. A bracket was installed alongside the pitted section and a cross feed mounted on it. Preparation of the surface was done in just the same way as described for the packing sleeves, using the square thread and special roughing tool. This shaft, too, was sprayed with the medium-chrome, medium-carbon stainless steel. The entire job took about 10 hours.

Rotating parts are by no means the only ones subjected to packing troubles. Figure 3 shows a hydraulic press ram being metallized with two guns simultaneously. Ram was first turned down to $27^7/_8$ in.

J. E. Wakefield is Asst. Sales Manager, Metallizing Engineering Co., Inc., Long Island City, N. Y.

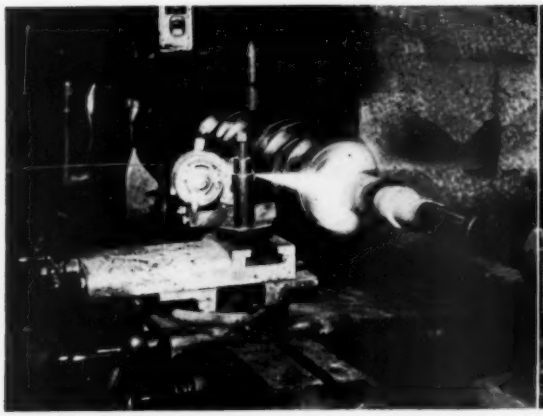


Fig. 1 Metallizing gun building up the worn packing sleeve of a centrifugal pump assembly. Stainless steel sprayed over the worn bronze will give three to four times as long trouble-free service life and save packing as well

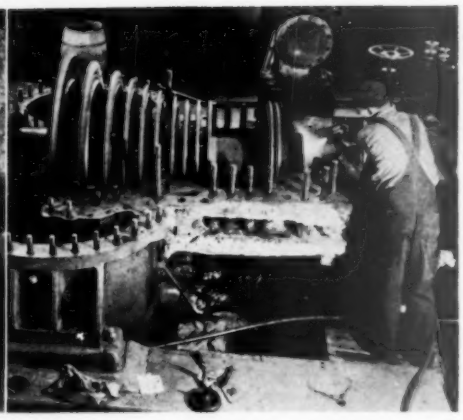


Fig. 2. Metallizing one of the badly fitted sections of a G. E. 2500 K.W. turbine shaft at a New England cement plant. Medium-chrome, medium-carbon stainless steel not only builds these back to size, but improves the wearing qualities as well

diameter by 7 feet. Undercut was not carried clear to the pressure end, however. It was stopped about 1/2 in. short. This prevented any possibility of the pressure working up under the coating and cracking or lifting it.

One other point of note on hydraulic ram work. Coatings should be at least 1/8 in. thick on the radius when finished. This prevents the pressure from working through the pores in the coating. It is a good idea to seal rams coated with stainless steel, as an added precaution. Raw tung oil, or raw or boiled linseed oil mixed with 5% by volume of cobalt liquid drier work quite well. Painting with oil should be done while the coating is still warm (but not hot) after spraying.

One large manufacturer of plastics materials has metallized several hundred similar rams. They vary all the way from 4 in. diameter up to more than 30 in., and operate under pressures from 1500 to over 4000 psi. The chrome carbon stainless steel not only prevents wear of the ram itself, but effects appreciable savings in packing, by keeping a smooth surface.

One thing to remember on reciprocating parts, pumps plungers, rams, piston rods, etc. Since excessive wear could cut through the coating along the surface and break the envelope of sprayed metal, it is better to put on heavier coatings than would be necessary for rotating parts. It is also better to use the threading and special roughing method of preparation,

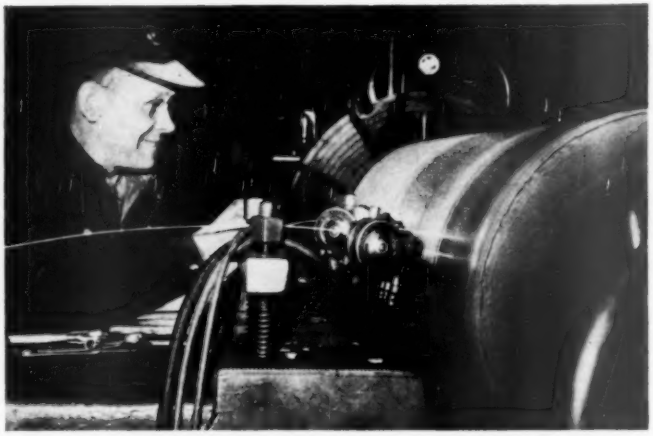


Fig. 3 Two metallizing guns rebuilding the pitted and scored surface of a large hydraulic press ram, used for forging steel into shafting for ships

as this prevents any creeping of the coating under the packing.

As far as selection of metal for metallizing is concerned on these surfaces, the medium chrome medium carbon stainless steel seems well worth its slight additional cost over carbon steels. It is hard, tough and resists the action very well indeed. Furthermore, it is sufficiently corrosion resistant to stand all ordinary corrosive action.

This type of stainless steel should be wet ground if possible. A fair finish can be obtained with cemented carbide tool bits, but rams usually need a pretty good finish. A wheel similar to Carborundum Co.'s G36-K4-VE Carborundum Vitrified or Norton Co.'s 37C46-K5V should be used for best results.

Packing areas certainly present a good application for metallizing. Only the limited areas are subjected to wear and corrosion as a rule, and need special protection.

the AMERICAN WELDING SOCIETY

activities • related events

A.W.S. 1949 Membership Directory

Now available to the Membership on request the 1949 Membership Directory contains the following:

Alphabetical list of Members
Geographical List of Members (by Sections)
Sustaining Member Data
Supporting Company List
Map Showing Distribution of Sections
Membership Reports as of June 30, 1949

SUSTAINING MEMBER

William F. Smith, School Administrator

The Lincoln-Gregory Trades School, Inc., Linden, N. J., was founded in 1938 for instruction in acetylene and electric arc welding, and has since gained nation-wide recognition for their most modern techniques in the teaching of heli-arc welding.

Special employee-training programs of welding instruction, are designed in conjunction with industrial management to meet the requirements of each company, thus enabling the client to save on labor and material costs.

The School is approved by the New Jersey Board of Education and the Veterans Administration.

MEMORIAL

George S. Herren

At a meeting of the Board of Directors of the AMERICAN WELDING SOCIETY held in Cleveland, Ohio, on Friday, May 13, 1949, the following Resolutions were unanimously adopted:

WHEREAS, the AMERICAN WELDING SOCIETY recognizes, in the death of George S. Herren, the loss of an active and valued member of the SOCIETY; and

WHEREAS, he was a founding member of the Columbus Section, its Secretary and Treasurer from the date of its founding in 1939 until his death and an active participant in Section activities during those years; and

WHEREAS, his unstinted efforts in the work of the Section aided materially in the growth of the Columbus Section, and thus in the growth of the SOCIETY; and

WHEREAS, his work, his cooperative spirit, and his friendliness endeared him to all those who worked with him; therefore, be it

Resolved, that the AMERICAN WELDING SOCIETY, through its Board of Directors, hereby expresses its sincere appreciation for George S. Herren's services to the SOCIETY; and be it further

Resolved, that this Resolution be spread upon the records of the SOCIETY, with expressions of sympathy and regret, and a copy of the Resolution transmitted to Mrs. George S. Herren and his family.

Above Resolutions prepared by Special Committee,
R. R. Grant, *Chairman*
C. B. Voldrich

Recommended Practices for Metallizing Shafts or Similar Objects

The AMERICAN WELDING SOCIETY Committee on Metallizing has just completed preparation of recommended practices on the above subject and is anxious to secure the comments from those in industry who are familiar with metallizing applications. If you wish to secure a draft copy of the *Recommended Practices for Metallizing Shafts or Similar Objects* write at once to: Simon A. Greenberg, *Secretary*, Committee on Metallizing, American Welding Society, 33 W. 39th St., New York, N. Y

American Welding Society Announces 1950 A. F. Davis Undergraduate Welding Award Program

Undergraduate authors of articles on welding appearing in undergraduate publications between Apr. 1, 1949, and Apr. 1, 1950, will be eligible for the $700 cash prizes in the 1950 A. F. Davis Undergraduate Award Program. The author of the best article on welding and the publication in which it appears will each receive $200. Duplicate prizes of $150 will be won by the author of the second best article on welding and the magazine publishing the article.

Sponsored by the AMERICAN WELDING SOCIETY the annual contest is open to any undergraduate of any college or university in the United States or its possessions and in Canada. The subject matter of the article may be on any phase of any type of welding or its application to design and construction.

The Award is named for its donor, A. F. Davis, Vice-President, The Lincoln Electric Co., Cleveland, Ohio. Judges are selected by the Educational Committee of the AMERICAN WELDING SOCIETY.

The complete rules of the contest will be sent on request to the AMERICAN WELDING SOCIETY.

Annual Meeting Papers

The Annual Meeting papers will be published as rapidly as possible. This issue contains seven such papers. Still more will be published in the October number. The National Program Committee is anxious to stimulate discussion of these papers to bring out all the pertinent facts in the most usable form.

It is the privilege and duty of every member of the SOCIETY to participate in such discussions if his experience makes it possible to contribute. Do you have additional information or data which would supplement information published by the author? Does your experience lead you to have contrary opinions or conclusions? Do you see a better way in which the task could have been accomplished? Could you arrange the information or charts in a clearer fashion? If the answer to any of these questions is yes—then why not contribute your discussion?

The method is simple—just send in your discussion and the necessary illustrations in duplicate. One copy will go to the author so he can frame a suitable reply if he so desires. The discussion together with the author's reply, if any, will be published in an early issue of the JOURNAL.

Importance of Welding to Management, the Engineer and the Public

A unique and outstanding session is planned for the coming Annual Meeting of the American Welding Society on Thursday evening, October 20th.

Colonel W. T. Chevalier, Executive Asst. to the President, McGraw-Hill Publishing Co. will present a comprehensive nontechnical dissertation on the importance of welding to management, the engineer and the consumer. He will cover developments in the automotive, heavy appliance, structural, home applances, transportation and other industries.

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INDEX TO ADVERTISERS

Air Reduction Sales Co.	Outside back cover
Aljay Manufacturing Co.	888
American Brass Company	Inside back cover
American Chain & Cable	881
The Bastian-Blessing Co.	882
Becker Brothers Carbon Co.	900
The Champion Rivet Company	884
Cullen-Friestedt Co.	889
Diversey Corporation	878
Dockson Corporation	888
Eisler Engineering Co., Inc.	895
Eldorado Mining & Refining	892
Electric Soldering Iron Co.	897
Fansteel Metallurgical Corp.	913
General Electric Co.	890, 891 and 914, 915
Harnischfeger Corporation	909
Hobart Brothers Company	815
The International Nickel Co., Inc.	816
The Lincoln Electric Company	879
The Linde Air Products Company	819
P. R. Mallory & Co., Inc.	817
Metal & Thermit Corporation	Inside front cover
National Carbide Corporation	885
National Cylinder Gas Co.	902 and 903
Oakite Products Inc.	900
Page Steel & Wire Division	881
Reed Engineering Co.	886
Ruemelin Mfg. Co.	887
A. O. Smith Corporation	898 & 899
Stulz-Sickles Co.	895
Tube Turns, Inc.	905
Union Carbide and Carbon Corp.	819
Victor Equipment Company	820
J. H. Williams & Co.	897
Worthington Pump and Machinery Corporation	883

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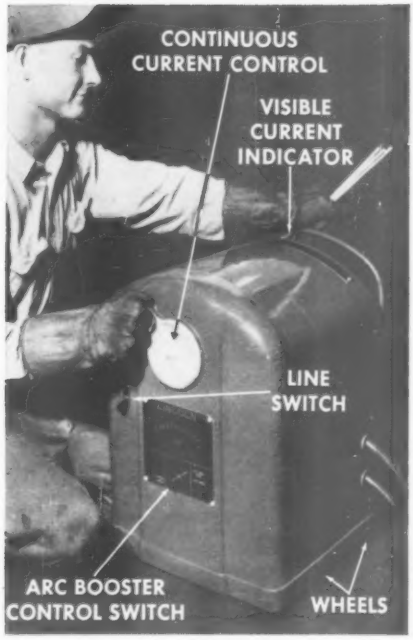

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Company _____ City & State _____

NEWS OF THE INDUSTRY

Steel Engineers Convention

The 1949 Annual Convention of the Association of Iron and Steel Engineers will be held in the William Penn Hotel, Pittsburgh, Pa., October 3rd, 4th, 5th and 6th. Over 3000 engineers and steel-mill operators from the iron and steel and allied industries are expected to be in attendance at this national convention.

With the ending of the seller's market in steel has come the need of exercising greater ingenuity and resourcefulness in bettering the economy of the industry's production. Stronger competition will call for improved quality and better operating efficiency, and these needs fall upon the shoulders of the engineering and operating personnel of the iron and steel industry.

To help meet these responsibilities, the Association of Iron and Steel Engineers is continuing to maintain its program of activities designed to inform the supervisors of the industry of the latest developments in equipment and processes. An important event in this program is the 1949 Annual Convention.

This meeting embraces approximately 40 technical papers by authorities of steel-mill engineering and operation, as well as two inspection trips. On October 4th, members and guests of the Association will visit the giant Irvin works of the Carnegie-Illinois Steel Corp. at Dravosburg, Pa. On Thursday, October 6th, they will visit the Aliquippa, Pa., works of Jones and Laughlin Steel Corp. At the latter plant they will view the world's fastest 42-in., 5-stand, tandem cold-strip mill.

On Wednesday afternoon, October 5th, M. W. Reed, Vice-President, engineering, United States Steel Corp., will address the entire group.

Society for Experimental Stress Analysis Meeting

The annual meeting of the Society for Experimental Stress Analysis will be held at Hotel New Yorker, New York, N. Y., on Nov. 30 and Dec. 1 and 2, 1949. Inquiries should be addressed to the Society for Experimental Stress Analysis, P. O. Box 168, Cambridge 39, Mass.

Cost Calculator

A cost calculator is announced by The Champion Rivet Co., Cleveland, Ohio, for computing time, electrode consumption and cost for most common groove and fillet welds. This calculator is printed in two colors on durable stock and measures 5½ x 9½ in. Information as to size electrode to be used, welding amperage, welding time, electrode consumption as well as cost on a particular joint are easily obtained by a simple setting of the slide chart. This attractive and useful item is available at a nominal charge of 50¢ each.

Lincoln Foundation Announces Awards to Engineering Undergraduates

Awards and scholarships totaling $6750 were presented by The James F. Lincoln Arc Welding Foundation to engineering colleges and undergraduates closing the 1948–49 competition of the Annual Engineering Undergraduate Award and Scholarship Program.

Funds for Scholarships totaling $1000 were awarded to the University of Wisconsin, Madison, Wis., $500 to the Case Institute of Technology, Cleveland, Ohio, and $250 to Iowa State College, Ames, Iowa. Scholarships established with these funds are to be named in honor of the engineering undergraduates receiving top honors in the program.

In addition to scholarship funds to schools, awards were also made to students in 47 engineering schools for the excellence of their papers submitted on arc-welded design, fabrication, maintenance and research.

The first award of $1000 was presented to Robert K. Allen and Alvin H. Kasberg, both seniors in the Department of Mining and Metallurgy at the University of Wisconsin. The subject of their paper for which the award was made was, "A Study of the Welding Characteristics of Aluminum-Bronze Electrodes." Four scholarships will be established at the University of Wisconsin in honor of these students.

A paper entitled "Design for the Welder," by George W. Grossman, a senior in the Department of Engineering Administration at the Case Institute of Technology, was given the second award of $500. Grossman will have two scholarships named in his honor at Case.

The $250 third award was presented to John B. Baer, a senior in the Department of Mechanical Engineering at Iowa State College for his paper entitled, "The Design of an Arc-Welded Forming Die."

In addition to these main awards, smaller awards were presented to 77 undergraduates. Total awards and scholarships for the program amounted to $6750.

The Annual Engineering Undergraduate Award and Scholarship Program is being sponsored by the Lincoln Foundation to stimulate engineering undergraduates, including agricultural and architectural, to investigate and aid in developing the science of arc welding and its application for the advancement of all industry.

Judging of the papers was conducted by Dr. E. E. Dreese, Chairman of the Board of Trustees of the Foundation and Chairman of the Department of Electrical Engineering, The Ohio State University. Dr. Dreese was assisted by Prof. B. H. Jennings, Chairman of the Department of Mechanical Engineering of the Technological Institute of Northwestern University and Prof. Frank D. Carvin, Director, Department of Mechanical Engineering of the Illinois Institute of Technology.

Inert Arc Gas Welders

Since April 1948, the Federal Communications Commission has had under consideration rules respecting radio interference which would affect the development and use of electric arc-welding devices utilizing radio frequency energy as part of the welding process. At a meeting of the Commission, held on July 6, 1949, the F.C.C. postponed the effective date of a proposed order applying such rules until Jan. 31, 1950. While this action allows the continued manufacture and sale of high-frequency stabilized arc-welding equipment for the next six months, the postponement was granted by the Commission to provide more time for further investigation of high-frequency stabilized arc welders and for further study of high-frequency radiation from this apparatus.

In this welding process, high-frequency current is used to stabilize inert-gas-shielded arc welding, particularly in the welding of aluminum and magnesium. The transportation, metal fabrication and chemical industries are using this process increasingly because it is one of the easiest and best methods of fabricating these metals.

The problem of radio interference attributed to this equipment has been studied intensively by the Joint Industry Committee on High-Frequency Stabilized Arc Welders, which is composed of manufacturers of high-frequency stabilized arc-welding equipment, metal suppliers and users of the apparatus. In view of the progress which has already been accomplished in the reduction of high-frequency radiation from these arc welders, it is hoped that a solution may be reached eventually which will permit the continued use of this welding method without interference to communications.

Budd Completes Delivery to New York Central

The Budd Co. has completed and delivered to the New York Central System the last of its recent order of 239 all-stainless-steel railway passenger cars, it was announced recently by Edward G. Budd, Jr., president. This was the largest order ever placed with Budd by one railroad.

In addition to 60 deluxe coaches, the order included 39 diners of different designs, 89 all-room sleeping cars, 26 lounge

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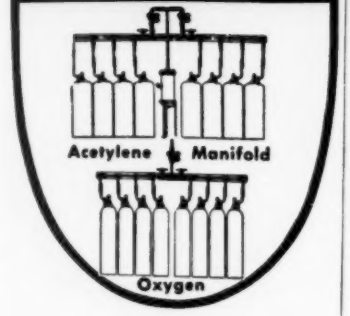

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combinations and 25 cars of miscellaneous types, and represents an investment by the New York Central of more than $22,000,000. The new cars have been used to re-equip a number of the New York Central's crack streamliners, including the Ohio State Limited, the Southwestern Limited, the Wolverine, the Pacemakers, the New England States Limited, Upstate Special (New York), Advance Empire State Express and James Witcomb Riley.

Prior to the war Budd built 36 cars for the New York Central, most of which made up the Empire State Expresses, whose preinaugural press run took place on Dec. 7, 1941.

Under construction on five assembly lines at this time are 95 cars for the Southern Railway System, Pennsylvania Railroad, Seaboard Air Line, Norfolk and Western, Missouri Pacific, Lackawanna and the Central Railroad of Brazil. Other railroads for which Budd has orders include the Southern Pacific, the Union Pacific and the Wabash.

Tempil® Distributor

Metal & Thermit Corp., 120 Broadway, New York 5, N. Y., have added Tempil® temperature-indicating products to the lines of welding accessories distributed by them.

Tempilstiks® and other Tempil® products are now stocked by Metal & Thermit's district offices and are also available from their distributors.

Peirce Laboratories

The establishment of the Peirce Memorial Laboratory of Metallurgy is an important milestone in the history of metallurgy at Stevens Institute of Technology, Hoboken, N. J. It is not only a fitting memorial to a great metallurgist, but provides the college with teaching and research facilities to meet expanding opportunities in this field.

It was ten years ago that the generosity and foresight of the late William H. Peirce, Stevens '84, made possible the first Stevens metallurgical research laboratory, known then as the Peirce Metals Laboratory. The new laboratory, established under a trust set up by Mr. Peirce, provides for the expansion of the work of the original laboratory. The Peirce Memorial, the Morton Memorial Laboratory of Chemistry and the newly constructed Kidde Memorial Laboratory of Physics, comprise the new Stevens Science Center.

Reducing Cost of Distribution*

American industry has made miraculous progress in reducing the cost of manufacture of its products.

Little progress has been made in reducing the cost of marketing and selling these products. At the present time it costs the consumer more to have products sold to him than it does to produce them. In many cases it costs ten times as much to distribute a product as it does to make it.

The next great step that will be taken in industry is to find methods whereby the cost of distribution can be tremendously decreased. Obviously, the saving which will be made here will be much greater in extent and in effect than any progress which can now be made in manufacturing. If the same ingenuity is used in development of distribution, as has been used in manufacturing, the price that the consumer pays for his products will be reduced by more than 40% which means the standard of living will be immediately greatly increased.

The Lincoln Electric Co. is giving much thought to this distribution problem. We are applying the same imagination to it as has been used in the development of our incentive system which so greatly decreases the cost and selling price of all our products.

The experiment which is being tried is in the sale of welders used on farms. The cost of distribution of farm machinery generally is even greater than that of the products used in the city. Hence, the opportunity is greater.

The first step we have made is to give to the farmer the money that usually goes to certain of those involved in normal methods of distribution. The plan cuts the price of the welder to the farmer by more than 25%, so that the Lincoln 180-amp. farm welder sells for $169.

Broadly speaking, the plan is to talk to the farmer at demonstration points where the utility and the methods of farm welding are shown to groups, rather than to individuals. This can be done at no greater cost than if the same demonstration were given to one.

The plan is undoubtedly merely a halting step in reducing the cost of distribution. The experience developed in this operation, however, will point the way to further economies which the company will adopt as their utility and effectiveness are proved.

The further economies inherent in this plan are far greater than the savings already achieved by it. How successful the plan is in achieving still greater economies depends on how cooperative the farmer will be in attending such demonstrations and learning the facts brought out in them.

* Highlights of an Address by James F. Lincoln, President, the Lincoln Electric Co., Cleveland 1, Ohio, at The Fourth Annual Estes Park Industrial Conference, Estes Park, Colo., July 15, 1949.

Pacific Industrial Conferences

"Twenty thousand chemists, chemical engineers and industrial executives from all over the nation and many other countries are expected to attend the Pacific Industrial Conferences which will run concurrently with the Pacific Chemical Exposition at the San Francisco Civic Auditorium, Nov. 1–5, 1949," says Dr. Richard Wistar, chairman of the California Section of the American Chemical Society.

1949 A.S.T.M. Annual Meeting

At the 22 formal technical sessions and the several informal sessions and roundtable discussions held during the 1949 Annual Meeting of the American Society for Testing Materials in Atlantic City,

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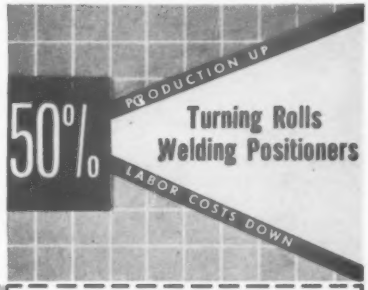

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June 27–July 1, upward of 185 papers and reports were presented. This was the 52nd Annual Meeting of the Society and notable progress was made in its research and standardization work in the field of materials.

On the recommendation of the A.S.T.M. technical committees 77 new tentative specifications and methods were approved, and almost 100 previous tentatives are to be adopted as formal standards. Many other specifications and tests were revised and brought up to date. All of these will be published in the 1949 Book of Standards to be issued in six parts late in the year.

Some idea of the intensive technical activity is given by the fact that there were 450 meetings of technical committees throughout the week.

The total registration for the meeting—1857, not including about 330 ladies—was the second high, exceeded only by the 1944 New York Meeting.

Lincoln Plant

The 20th anniversary of welding in American construction industries was signalized by ground-breaking for the new $8,500,000 all-welded, single-story plant to which The Lincoln Electric Co., will transfer all of its manufacturing of welders and electrodes in 1950.

The Austin Co., which erected the four-story framework for the country's first commercially welded building (Upper Carnegie Bldg.) here in the summer of 1929, designed and is building the new Lincoln plant.

Structural steel for the new plant will be fabricated at the Austin Company's Bliss Mill, located 3000 ft. from the site of the new plant. Austin officials estimate that the use of welding, which eliminates the need for gusset plates and other structural items, has resulted in savings of over 10,000 tons of steel in the past 20 yr. at the Bliss Mill alone.

George A. Bryant, Austin president, stated that the new Lincoln plant will be constructed almost entirely from standard jig-fabricated H-section trusses, as a cumulative result of Austin's research in welded design and the application of mass production techniques to steel fabrication.

The German Welding Society

Commencing in January 1949, the German Welding Society published a new welding magazine *Schweissen und Schneiden* (*Welding and Cutting*). The previous welding magazines in Germany ceased publication in the winter of 1944–45. In May 1947, the two German welding groups united for form a single Society. The new magzine deals with all branches of welding and cutting and is edited by Dr. H. Koch in Hanover.

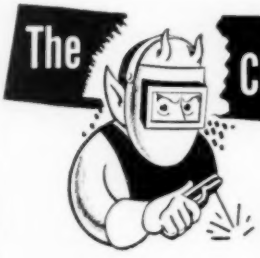
The Swiss Acetylene Society

The annual report of the Swiss Acetylene Society for 1948 commences with the statement that while business in general slowed down somewhat during the year, there was no unemployment. Production of carbide and consumption of acetylene and oxygen increased slightly in Switzerland compared with 1947. The Society gave 35 welding courses attended by 505 students, an increase of 50% over 1947. The Society *Journal* contained 254 pages of text during the year. Of the subscribers to the *Journal* 40% are artisans, another 40% are employed in plants and factories, while the remaining 20% are engineers and technicians in public departments, railways, etc. An intensive membership campaign raised the total membership by 91 to 1288. The Society has enlarged its technical library, and inspected 394 acetylene installations.

A.S.T.M. Establishes General Requirements for Rolled Structural Material

The action by the American Society for Testing Materials, on the recommendation of its Committee A-1 on Steel, in establishing a new specification involving general requirements for delivery of plates, shapes and bars, A 6, which document incorporates much of the material common to the several individual structural specification, is considered a very significant one, and its application and development will be watched with much interest, not only in the steel industry, but by a number of the other A.S.T.M. technical groups. Concurrent with the removal of tolerance tables, testing details, etc., from such

The CHAMPION of all general purpose electrodes



IS THE

GRAY DEVIL #2

AWS CLASS E 6012

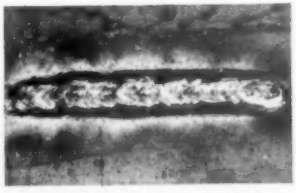
D. C. Straight Polarity (May be used with A. C.)

Welding supervisors have long sought an all-purpose electrode which would withstand high currents without loss of efficiency—THAT'S GRAY DEVIL #2!

Operators have always wanted a straight polarity rod which could be used with plenty of heat without the usual penalty of excessive globular spatter—THAT'S GRAY DEVIL #2!

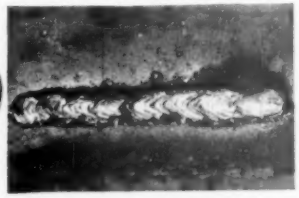
Welding engineers have required a general purpose, poor fit-up electrode which would consistently produce good quality welds of uniformly smooth appearance, excellent slag characteristics and ease of handling in all positions—THAT'S GRAY DEVIL #2!

Send for free samples—try them and be convinced



Above: CHAMPION Gray Devil #2. Note absence of spatter at high amperage.

Below: Typical of many comparative electrodes tested. Note heavy globular spatter.



THE CHAMPION RIVET COMPANY

CLEVELAND, OHIO EAST CHICAGO, IND.

New slide rule type Welding Cost Calculators available 50¢ each.
Send for one of these great time savers.

specifications as A 7, covering steel for bridges and buildings, one of the oldest A.S.T.M. documents, and other important standards such as that for locomotives and cars, A 113, and the others noted, essential requirements were studied and clarified.

This study began in 1947 when it was realized that to incorporate in each individual specification all of the various tables and general requirements necessary to cover rather completely the necessary quality and related values, would mean a great amount of printing and considerable duplication among the standards. Subcommittee II on Structural Steel discussed the matter at several meetings with voluminous correspondence, and with the approval of the A-1 Advisory Committee, and eventually the main committee, established a so-called "General Specification," which is essentially part of the other product standards, and to which they refer. Chairman of Subcommittee II at the time the move was started was F. H. Frankland. His successor, C. E. Loos, Carnegie-Illinois Steel Corp., and Jonathan Jones, Fabricated Division, Bethlehem Steel Co., Inc., very active in the work of Subcommittee II for many years, and its vice-chairman, have had a leading part in this important activity. The scope clause of the new general requirement specification A 6 is as follows:

Scope

1. This specification covers a group of common requirements which, unless otherwise specified in the purchase order or in an individual specification, shall apply to rolled-steel plates, shapes and bars under each of the following specifications issued by the American Society for Testing Materials:

Title of specification	*A.S.T.M. designation**
Steel for bridges and buildings	A 7
Structural silicon steel	A 94
Structural steel for locomotives and cars	A 113
Structural steel for ships	A 131
Low-alloy structural steel	A 242
Structural rivet steel	A 141
High-strength structural rivet steel	A 195
Low and intermediate tensile strength carbon-steel plates of structural quality	A 283
Intermediate tensile strength carbon-silicon steel plates for machine parts and general construction	A 284

* These designations refer to the latest issue of the respective specification.

While the changes in the condensed and revised product specifications, such as A 7 (first printed in 1899 and adopted in 1901), in general result from the removal of material now in A 6, other changes have been incorporated and numerous editorial clarifications have been made.

It can be said of these new specifications, that they now include most of the important requirements necessary for the designer and purchaser to get required quality from the materials. They include material that formerly was not a part of the standards, and it is believed the product specifications will be easier to use, and clearer because of the concentration on the essentials.

This move of establishing a specification with material common to several other product standards is being studied in other Committee A-1 groups, including Subcommitee XI on Steel for Boilers and Pressure Vessels, and Subcommittee IX on Pipe and Tubing.

These new and revised structural steel specifications are being issued together in a pamphlet of about 36 pages so that the purchaser of the product specification will always have A 6 as part of the pamphlet for handy reference.

One leading authority who has had an important part in the work believes that this move will give documents that are of greater convenience to both producer and user. The producer will know that the standard tolerances have been accepted by the user, and the user will, through representation in the A.S.T.M. committees, be able to check and discuss, and improve tables and general conditions before they are standards. In general, the new setup will provide a more satisfactory background to the whole relationship between the producer and consumer of structural steel.

Copies of the pamphlet, giving the ten revised specifications including A 6, can be obtained from A.S.T.M. Headquarters,

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ECONOMICAL
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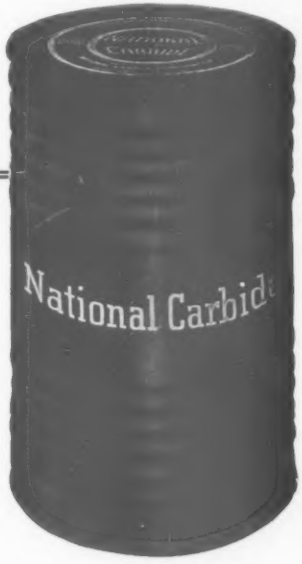

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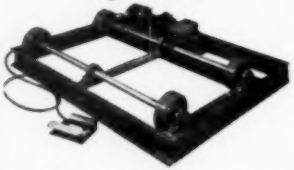

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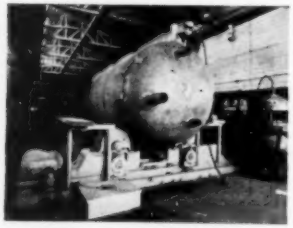

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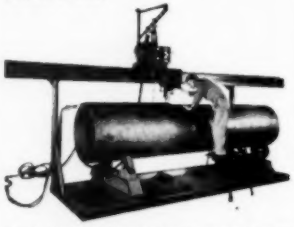

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CARTHAGE, MISSOURI, U. S. A.

1916 Race St., Philadelphia 3, Pa., at $1.00 each. Reduced prices for orders in quantity.

New Generating Station

Upon completion of four units, Sewaren Generating Station will have an installed capacity of approximately 450,000 kw. and will be the largest of the five major generating stations which serve the Public Service Electric and Gas Co., of Newark, N. J. Its location on the Arthur Kill, 3 miles above Perth Amboy, is north of the system's geographic center and south of its load center.

Of special interest to our readers are the transition from ferritic to austenitic steel pipe at turbine stop valves and the welded aluminum bus bars. Both are described below.

Piping Systems

The piping systems of the plant are made up with the widest practicable use of welded joints. The only flanged joints exposed to 1050° F. steam are those in the steam admission pipes from the turbine control valves to the top half of the high-pressure turbine casing. In the high-pressure boiler feed piping there are no flanged line joints. Valve bonnets in this system are of the pressure-sealing, breechblock design without a bolted closure. In the larger sizes, the piping systems carrying salt water are of cement-lined steel, with welded joints. The 48-in. circulating water pipes are made of reinforced concrete.

There are no valves between the boiler and the turbine stop valves in the main steam system. The pipe is made of 3% chromium, and 1% molybdenum alloy steel. The main run is 16½ in. in outside diameter, forged and bored to 2¾-in. wall thickness. The turbine stop valves are made of stainless steel which expands about 50% more than the ferritic steel of the pipe. The welded joint between the two was made in the shop by a new method known as the "Kelcaloy Process" developed by The M. W. Kellogg Co., illustrated in Fig. 1. The purpose of this arrangement is to have the major portion of the interface between dissimilar metals longitudinal to the pipe rather than transverse, and therefore subject principally to shear stress as a result of internal pressure or bending forces.

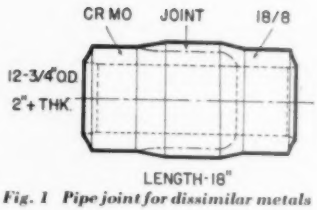
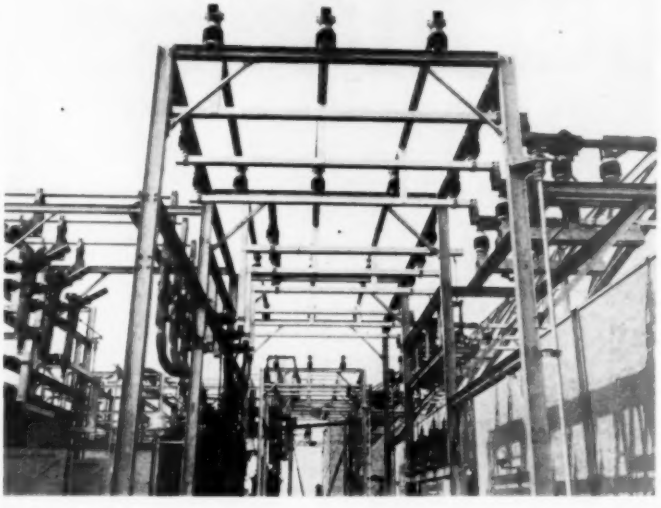


Fig. 1 Pipe joint for dissimilar metals

The piping and valving of the feedwater system have been simplified by locating the heaters in pairs, placing more heaters on the suction side of the boiler feed pump, and locating three of the low-pressure heaters in the condenser neck.

Aluminum Bus Bars

The main generator 13-kv. leads from the machine terminals to the reactor midtap are designed for 5000 amp. The bus from the reactor end terminals to the low-voltage bushings on the 13–132-kv. transformers and to a "Y" point on the feed to the 13–26-kv. transformers is designed for 4000 amp. From that same Y point to the low-voltage bushings on the 13–26-kv. transformers the bus will carry 3000 amp. All sections are aluminum and



13-Kv., 3000-Amp. Welded Aluminum Bus Consisting of 5 by 5 by 3/8 In. Square Tubing

designed to withstand a short-circuit current of 66,000 amp. The 5000-amp. bus consists of two 6- x 4- x $^{7}/_{16}$-in. angles clamped to form a square with the 6-in. leg horizontal. The 4000-amp. section is a 6- x 6- x $^{3}/_{8}$-in. square tube and the 3000-amp. bus a 5- x 5- x $^{3}/_{8}$-in. square tube. Since maximum conductivity is desired, pure aluminum having a conductivity of approximately 58% that of copper is used.

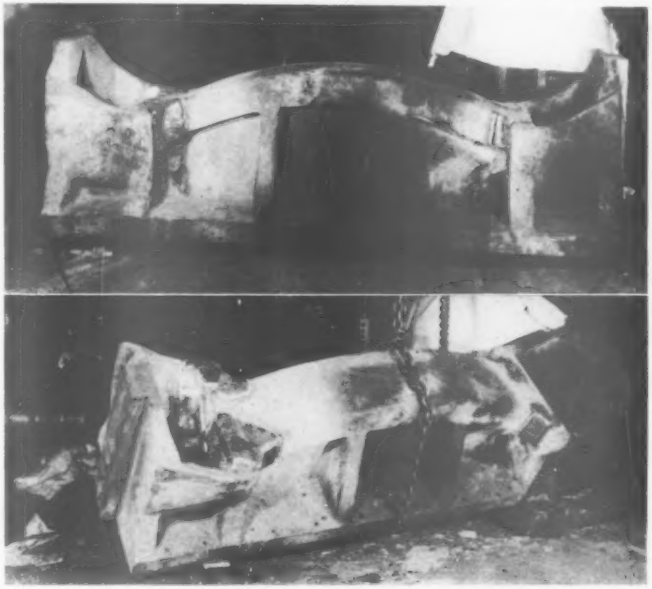
All connections on the aluminum bus itself are welded by the shielded, inert-gas process of a.-c. welding. Splice plates are used on all joints to give better current distribution as it is assumed that all current is carried through the weld and not across adjacent contact surfaces from which it is impossible to remove the aluminum oxide.

The 132-kv. bus, is of entirely different construction as it carries only 1200 amp. but must span 33 ft. between bus supports. A 4-in. O.D. aluminum tube with $^{1}/_{8}$-in. wall is used. The end connections are butt welded and are made with an inside reinforcing sleeve approximately 12 in. long. All taps to this bus are above and at right angles to the main run with an "A" type connection having two legs of $1^{1}/_{4}$-in. I.P.S. aluminum at 15° to the vertical. The single top connector and the two bottom connectors are made of cast aluminum and are welded to the tubing.

Repairing 15-Ton Casting

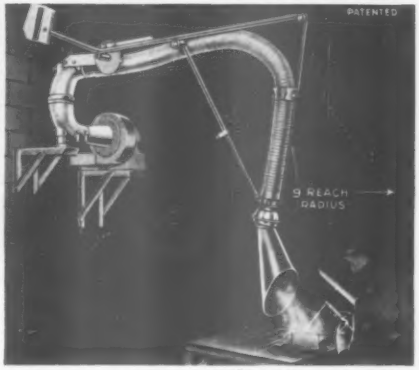
Shown below two photographs of a 15-ton casting.

These pictures are of a Ram for a large punch press which was welded by superior Welding & Brazing Co., 6538 Russell St., Detroit 11, Mich. The breaks through the Pitman Housing on one end and also the cracks ahead of the Pitman Housing at the other end were repaired by bronze welding.



RUEMELIN Fume Collector

(Above) Welding without ventilating snout. Note smoke clouds and poor vision. Gases and heat surround operator's helmet.



(Right) Collecting fumes with a Ruemelin Fume Collector.

REMOVES WELDING FUMES *at the Source!*

Solve your welding fume problem efficiently by installing Ruemelin Welding Fume Collectors. They produce a powerful suction that removes smoke, gas and heat at the source. Guards employee health, resulting in less welder fatigue. Clears shop air with minimum heat loss. Covers maximum welding area vertically, horizontally and by circle swing. Made in 9 ft. and 15 ft. reach sizes. Shipped assembled, easy to install. Thousands in practical service. Free engineering service for your installation.

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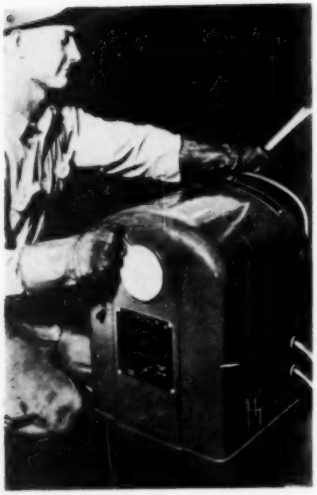
Low Cost A.-C. "Fleetwelder"

A record low price on its new model 200-amp. a.-c. industrial type welder is announced by the Lincoln Electric Co., Cleveland, Ohio. "The Fleetwelder 200," a N.E.M.A. rated unit with plenty of reserve capacity over its rated maximum load of 250 amp., is available at a cost of $180, less than $1.00 per ampere of N.E.-M.A. rated output.

Because of its exclusive arc booster and outstanding reserve capacity, the unit is ideally suited for both job shop welding and industrial welding. It can handle an exceptionally wide range of work in thick as well as thin material. Electrodes ranging in diameter size from $^{5}/_{64}$ to $^{1}/_{4}$ in. may be used with it. For applications where the advantages of a.-c. current are indicated, the Fleetwelder will supply the modern demand for lower cost, more versatile welding.

Low-current welding of thin sheets is simplified and high-current welding of heavy plate is made faster through Lincoln's arc booster. The arc booster adjusts the welder to start the arc automatically the instant the electrode touches the work on either thin or heavy material. The arc is given an extra burst of current which starts the arc and secures penetra-



tion at the start of the weld. The current automatically returns after a few seconds to the correct amount set for the job.

Continuous fine adjustment of the welding current through the complete range is secured by a few turns of the control handle on the front of the case. A readily visible dial on top of the case indicates the current setting. Because of its unique electrical design, the Fleetwelder has a lower open-circuit voltage than is normally required, which reduces power consumption, operating costs and means the welder is absolutely safe to use.

The compact design of the welder allows the entire unit to be enclosed in pressed steel case standing only 25 in. high. The patented reactor control eliminates dead air space which is normally needed for other types of control. There are no moving coils or leads in the windings and both coils and control reactor are firmly clamped in position to give lifetime, vibration-free service. Heavy copper windings are insulated with spun glass and mica separators, placed in a welded steel-laminated frame.

The unit is equipped with wheels for portability at no extra cost. Total weight is 319 lb.

Welded Building

Welding in building construction continues to play a major role in development of the skyline in the City of Houston. The most recent multiple story frame to be completed is a 16-story office building two blocks off Main St., on Texas Ave. This structure is comparatively small in floor area, measuring only 50 x 125 ft. and is being erected to provide additional office space for firms in adjoining buildings.

Architectural design has been handled by J. Russ Baty, and the engineering work was done by Robert J. Cummins. The general contract for this building was

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awarded to W. S. Bellows Construction Corp. with a subaward to Peterson Brothers for field erection and welding of structural steel. Shop and field welding was done in accordance with the A.W.S. Code for Arc and Gas Welding in Building Construction under supervision of Southwestern Laboratories.

The engineering design makes use of rigid connection of all beams framing to columns, with butt welds on flanges and a fillet welded shear connection in the web. Intermediate beams were fabricated with flexible connections, and column splices are standard milled ends with splice plates on flanges and in the web.

Heliarc Welding Aluminum Hull

A Novel Heliarc Job

The city of Detroit, as well as being the automotive center of the nation, is the power-boat racing center, also.

Deluxe Welding Co., 3940 Connor Rd., Detroit 14, Mich., submitted the photograph above showing the Heli-Arc welding on the aluminum-clad hull of the *Miss Michigan*, a new boat being built for the several races held on the Detroit River, annually.

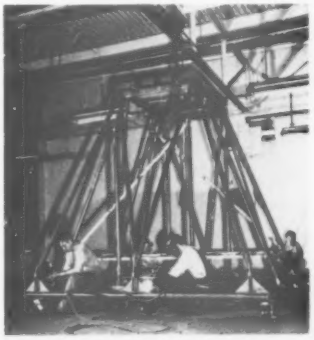
The oak frame and planking were covered with $\frac{1}{8}$-in. thick aluminum sheets, requiring 125 ft. of corner welding, 85 ft. of filet welding and 92 ft. of butt welding, to close all seams.

Miss Michigan, which has a beam of 13 ft. 6 in. and a length of 34 ft., will be powered by two Allison engines developing a total of 3500 hp., and is expected to attain speeds from 90 to 100 mph.

As pictured, the view is from the left rear corner of the hull, which is inverted on a trailer.

Welded Bomb Racks

One of the largest certified welding jobs ever undertaken by an aircraft manufacturer—over $2\frac{1}{2}$ miles of certified weld were required—is nearing completion at Texas Engrg. and Mfg. Co., Inc., Dallas, Tex., where final units of a contract calling for 160 B-36 bomb-bay tank storage racks now are being delivered.



The racks—part of the specialized handling equipment being built for the B-36—are of arc-welded pipe construction throughout, 3-in. black pipe being used for the base and 2-in. black pipe for the superstructure. Each unit measures 10 ft. $11\frac{1}{2}$ in. by 11 ft. $3\frac{1}{2}$ in. at the base, stands 9 ft. $8\frac{1}{2}$ in. tall, weighs approximately 2000 lb., and requires 1006 in. of weld.

Under Air Force specifications all welding had to be certified. Consolidated Vultee Aircraft Corp., prime contractor on the B-36, subcontracted the racks to Temco where certified aircraft welders were used for their fabrication.

Temco's welding department is one of the most complete in the Southwest, and includes U.S.A.F. certified welders for oxyacetylene, oxyhydrogen, metal-arc and arc in inert atmosphere (heliarc) welding of carbon and alloy steels, corrosion resisting steels and aluminum alloys and U.S.A.-F. certified equipment for spot welding stainless steel and aluminum.

When a touch on a button moves weldments like these into the correct, most convenient position for a downhand pass, you get more arc time, more welding at lower cost. C-F power operated Positioners rotate the work in a full circle at any point in a range of 135° from the horizontal—giving welders a choice of an infinite number of downhand welding positions instantly.

Every requirement for faster, better positioned welding—constant or variable speed table rotation, full 135° tilt, self-locking gearing which holds the table in any position, oversize built-in main tilt and rotating bearings, choice of two base styles, and many other features—are built into C-F Positioners.

C-F Positioners are available in Hand or Power operated models, and are made in capacities up to 30,000 lbs. and larger.

Write for the new C-F Positioner Catalog.

1323 S. Kilbourn Ave. Chicago 23

C-F positioned welds mean better, more economical welds

CULLEN-FRIESTEDT CO., CHICAGO 23, ILL.

Annual Meeting
American Welding Society
Cleveland, Ohio
Oct. 16–21, 1949

Less "pickup" Less "splatter"

Use G-E slope control for resistance welders

Tip "pickup" in spot-welding aluminum and expulsion in projection welding is reduced with this new Slope Control developed at General Electric. It is a method of applying current in gradually increasing intensity that results in longer operation of electrodes without the frequent cleaning usually required.

Here, again, is evidence of the research continually conducted at General Electric to improve welding methods—to make the production of improved products easier and less expensive. Here are the answers to the questions we knew you'd ask about Slope Control.

Q. What is Slope Control?

A. It is supplementary equipment used with a standard synchronous or non-synchronous precision control panel that regulates the rate at which current rises to welding value, and is adjustable in terms of cycles to reach final current.

Q. What effect does this have on the finished weld, and is it slower?

A. Our tests have shown that there is less tendency for porosity, which means stronger welds, and that it does not appreciably slow the work. See the cross sections of welds made with Slope Control.

Q. Can I use it on my present G-E electronically controlled welder?

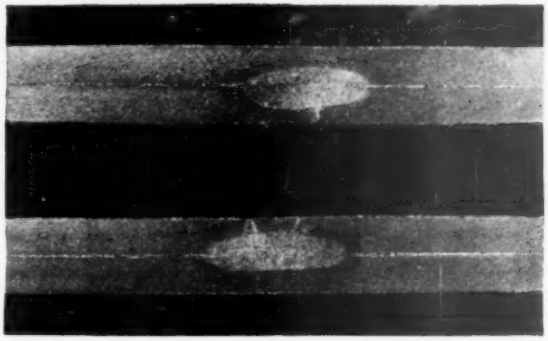
A. Yes. It is a separate panel that can be easily added to most modern G-E controls.

Q. With what types of welders and metals can it be used?

A. Use it for spot-welding aluminum (see the illustration), for projection welding aluminum or steel (it reduces expulsion), and for multiple projection welding, where you'll find improved results on non-uniform projections. It may be used with almost any metal, but aluminum and its alloys present a tough problem it can solve.

More details on G-E slope control in Bulletin GEC-534. Fill in and send in the coupon now. And when you have control problems for resistance welders, consult the nearest G-E sales engineer. He'll give you an unbiased answer based upon years of G-E experience with all types of welding. Whether it's a power factor problem, or the selection of the most suitable control for a specific job, you can be sure of your facts when they come from General Electric. *Apparatus Dept., General Electric Company, Schenectady 5, N. Y.*

Cross sections of aluminum spot welds produced with slope control (a microphotograph).



GENERAL ELECTRIC

Whether you're welding aluminum or heavy gage steel

...THIS IS FOR YOU

Projection welding with synchronous precision control. Slope control is mounted in side door of unit (small door open). Can also be used with standard 60-cycle spot welders having non-synchronous welding control.

Splatter reduced. Compare surfaces of these aluminum plates. Above, welds produced with single-phase, synchronous projection electric controls. That at left, with the addition of slope control.

ASK TO SEE "This is Resistance Welding," General Electric's More Power to America, four-color, sound motion picture covering every phase of this manufacturing process. Contains tips for improved production for operators of machines, design engineers, and supervisors. Contact your Resistance Welder manufacturer, Power Supplier, or the nearest G-E office.

Tip pick-up reduced. Electrode on left has been used 117 times with slope control. That at right used 41 times without slope control. Note wide area of aluminum pick-up.

General Electric Co., Sec. D645-50
Schenectady 5, N. Y.

Please send me Bulletin GEC-534 on Slope Control.

.....I would like a showing of "This is Resistance Welding."

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ADDRESS .....

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(*Continued from page 840*)

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NEW LITERATURE

Structural Design in Metals

Structural Design in Metals, by Clifford D. Williams, Head Professor of Civil Engineering, University of Florida, and Ernest C. Harris, Chairman, Department of Structural Engineering, Fenn College. This book received first award in the Structural Design Division of the competitive program for modernized textbooks on design sponsored by The James F. Lincoln Arc Welding Foundation. This book of 596 pages sells for $6.50. The authors have attempted in *Structural Design in Metals* to provide the material for a coordinated course of instruction in that subject for students at the level of the Junior year in the average engineering college. An attempt is here made to analyze both welded and riveted details in each phase of work.

The place or rigid-frame design has become more and more important during the past few years. The chapter on "The Rigid Frame," has been included to provide material for those schools that have included analysis of statically indeterminate structures in the course of study.

There are, in addition, special sections relating to Welding, Selection of Sections, Connections, Girders, Trusses, Light Structural Members, Fatigue of Structural Members and appendices including the various codes. Published by The Ronald Press Co., 15 E. 26th St., New York 10, N. Y.

Weldirectory for Mild Steel

The Lincoln Electric Co., Cleveland 1, Ohio, has just issued one of their attractive technical bulletins, No. 462, giving complete information on mild-steel electrodes. The bulletin includes a guide for the selection of Lincoln electrodes for various requirements. This is followed by complete technical information with illustrations on procedure pointers for shielded arc welding. Complete technical information is given on the "Fleetweld" electrode corresponding to the various A.W.S. classifications for mild steel. Information is also given on the welding of chromemoly steels, steels of poor weldability and high-tensile steels.

Handbook of Steel and Steel Products

The intention of this handbook has been to present a comprehensive picture of the whole field of British steel products and to give in summarized form all the standards that apply to them. Its compilation has been a cooperative effort of the whole of the British Steel Industry, acting through an editorial committee under the chairmanship of Sinclair Kerr of the Lancashire Steel Corp., and T. Jolly of Guest, Keen & Baldwin's Ltd.

There are three main parts to the book, and an index. The parts are:

1. Articles describing the manufacture of steel and of steel products.
2. Classified summaries of the essential technical requirements of British standards for steel and steel products.
3. Other information of general interest e.g., methods of test, heat treatment definitions and conversion factors.

Published by The British Standards Institution, 24 Victoria St., Westminster, S. W. 1, London (B. S. Handbook No. 10), 674 pp., 8½ x 5½ in., stiff cloth covers Price: £1 5*s*.

Stoody Guidebook

A revised edition of the *Stoody Guidebook* covering applications of hard-facing alloys in heavy industry has recently been published. This booklet provides detailed information on the choice and application of various hard-facing metals commonly used in heavy construction, mining, cement, brick and clay plants, dredging, rock products plants and similar operations.

Approximately 100 common uses for hard metals are described; data includes types of metals recommended, the method of application and the approximate amount of alloy required for the job in question. Copies of the *Guidebook* are available without cost to all operators who request them from Stoody Co., Whittier, Calif.

Steel Castings

Substantial savings made possible by the use of steel castings in virtually every phase of basic manufacturing operation in this country are emphasized in a new illustrated booklet published by the Steel Founders' Society of America.

Prepared for distribution to members of the industry, design engineers, management executives, editors and writers, educators, students and other interested individuals and groups, the 34-page booklet directs particular attention to the versatility, strength and dependability of steel castings, and the enviable performance record of millions of steel castings proved in exacting service during the last 50 yr. of American industrial growth.

Lifters

The Pucel Enterprises, Inc., 3746 Kelley Ave., Cleveland 14, Ohio, have issued a four-page attractive circular describing a new type of Gonser grizzly lifters. This new type of lifter eliminates chains, pinch bars, slings, ropes and clamps. These new lifters are especially designed for welding operations and will save labor, time and money. The special design permits adjustments to maintain perfectly balanced lifting and lowering of work at any desired angle regardless of weight distribution.

Metallizing

The July issue of the *Metco News* reports that users of metallizing have found repairing journals with metallizing a very profitable maintenance operation. For instance, a large Canadian paper mill uses 18-ton vacuum seal rolls, 30 x 248 in., with 10.829 in. diameter x 23¹/₄-in. antifriction bearing journals at both ends. The previous practice of turning down the journal diameters and fitting with undersize split sleeves was never satisfactory. It caused much wasted time and confusion every time one had to be replaced. Eventually, the journals would have to be scrapped and replaced at $1115 each. Add the savings by metallizing over old repair methods, and there is a total saving of $18,840.

Textile plants cannot use as much oil as they would like—because of this, they have a serious problem with journal wear. Journals of beater shafts, comb shafts, Lickerin rolls and many other types of journals wear and have to be reclaimed. The *Metco News* shows, for example, a card feed roll journal. A journal like that takes 50¢ worth of metal—17 min. to prepare, spray and finish. Soaked in graphited oil, this journal will run without wear many times longer than it originally did.

Metallizing also saves time and money for the printing industry in a wide range of journal repair jobs. The world's largest supplier of new and rebuilt printing equipment uses metallizing in getting many different types of journals back into shape as good as new. This supplier offers money-back guarantee on all metallized rebuilt products.

Many other applications are also suggested such as air compressor parts, boring bars, cam shafts, hydraulic rams, mandrels, patterns, pulleys and squeeze rolls. Write for your copy of the *Metco News*, Vol. 4, No. 9. Metallizing engineering Co., Inc., 38-14 30th St., Long Island City 1, N. Y.

Arc-Welding Accessory Catalog

A new 20-page catalog containing descriptions, specifications and prices of more than 150 arc-welding accessories has been announced as available from the General Electric Co., Schenectady 5, N. Y.

Designated as publication GEC-253A, the new bulletin includes information on electrode holders, helmets and goggles, tungsten electrodes, all types of protective aids and clothing, electrode carriers, cable connectors, ground clamps, brushes, cleaning tools, fillet weld gage and many other accessories for the arc-welding operator.

PERSONNEL

Bain Honored

Dr. Edgar C. Bain, Vice-President, Carnegie-Illinois Steel Co., will receive the 1949 Gold Medal of the American Society for Metals, according to an announcement recently made by W. H. Eisenman, National Secretary for the Metal's Society. Dr. Bain receives this, one of the highest honors made available in the metals industry, in recognition of his great versatility in applying science to the metal industry.

Presentation of the Gold Metal to Dr. Bain will be made at the annual dinner of the American Society for Metals, to be held in the Grand Ballroom of Cleveland's Hotel Statler, Thursday evening, October 20th, during the 31st National Metal Congress and Exposition.

The Gold Medal of the American Society for Metals was established in 1943 to recognize outstanding metallurgical knowledge and exceptional ability in the diagnosis and solution of diversified metallurgical problems.

Dr. Bain is a Past-President of the American Society for Metals and has made many notable contributions to the art and science of Metals through his active membership in the Society. The 1949 A.S.M. Gold Medalist was the Edward deMille Campbell lecturer at the annual A.S.M. meeting at Buffalo, N. Y., in 1932.

Dr. Bain was the recipient of the American Society for Metals' Distinguished Service Award in 1948 for his meritorious contribution to progress in alloy steels.

F. Malcolm Farmer Elected New President of E.T.L.

F. Malcolm Farmer, vice-president of Electrical Testing Laboratories, Inc., New York, has been elected president of the company. He succeeds the late Preston S. Millar. Mr. Farmer has been connected with E.T.L. activities since 1903, becoming chief engineer in 1911 and vice-president in 1929.

During the recent war Mr. Farmer served as technical consultant on inspection methods, New York Ordnance District, U. S. Army, 1942–45, and was awarded a War Department Certificate of Commendation for his services.

In the course of his career, Mr. Farmer has served as president, American Institute of Electrical Engineers, American Society for Testing Materials, American Welding Society and United Engineering Trustees. He has also served as chairman of the Engineering Foundation.

J. W. Bramley Appointed Manager

The appointment of J. W. Bramley, of Boylston, Mass., as manager of The Babcock & Wilcox Tube Co.'s new Boston District Sales Office was announced recently by Edward A. Livingstone, Vice-President of the Company.

Mr. Bramley attended Ohio Wesleyan University, Delaware, Ohio. From 1937 to early 1949 he was with The Lincoln Electric Co. and J. E. Raney & Co., being associated the last 9 yr. with their technical sales divisions in the New England district. He is a past-director of the Worcester, Mass., section of the American Welding Society.

Mr. Bramley will have his headquarters in the Boston offices of the Company at 250 Boylston St.

American Brake Shoe Promotions

Joseph H. Parsons and Robert B. Pogue have been appointed Vice-Presidents and Rosser L. Wilson has been appointed Chief Engineer of the Brake Shoe and Castings Division of American Brake Shoe Co.

Mr. Parsons, formerly Assistant Vice-President, will be in charge of miscellaneous castings sales.

Mr. Pogue, formerly Chief Engineer, continues in charge of engineering. He has been with the Brake Shoe Co. since 1916 and Chief Engineer of the division since 1937.

Mr. Wilson, formerly Assistant Chief Engineer, joined the company as an engineer in 1935.

Zapffe Honored

Dr. Carl A. Zapffe, member, and Miss M. E. Haslem have been notified by the Board of Directors of the Wire Association that they have been awarded a Certificate of Honorable Mention for presenting the outstanding paper to the Ferrous Division of that industry in 1948. The paper, presented to the Annual Meeting in Pittsburgh on Oct. 19, 1948, described the discovery that hydrogen gas is absorbed by certain steels from inhibited pickling solutions in quantities as great as from uninhibited acids, causing important damage which has previously been blamed on other factors. The research, conducted in conjunction with an Office of Naval Research contract for the past several years, went on to describe a corrective inhibitor of undisclosed composition.

Dr. Zapffe and Miss Haslem will be presented with this award at the Annual Banquet of the Wire Association in Chicago on Oct. 19, 1949.

C. T. Posey Made Mid-West Field Engineer for Arcos

C. T. Posey has been appointed Field Engineer in the Midwestern area for Arcos Corp., with headquarters at 1324 Fulton St., Chicago 7, Ill. He will assist the Arcos distributors in this area, Machinery and Welder Corp. and C. E. Phillips & Co., in their stainless-steel electrode sales activities. Mr. Posey has been associated with Arcos Corp., since 1946, as Field Engineer.

Charles Freeman Joins Reed Engineering Co.

Charles S. Freeman has been appointed sales representative for the Reed Engineering Co., of Carthage, Mo., on turning rolls and special welding jigs and fixtures in the Buffalo, N. Y., area. Mr. Freeman was formerly with Lincoln Electric Co., where he started his employment in 1920. In 1924, he was sent to their Philadelphia office as a welding engineer and in 1927 was made district manager in charge of the Buffalo and Northern Pennsylvania territory. In 1930, the Northern Pennsylvania territory was set up under a separate office and he remained as district manager in Buffalo covering Western New York.

Mr. Freeman left Lincoln Electric Co., in March 1948, to start his own business as a manufacturers agent and welding

consultant. He has been active as a consultant on welding problems and welding design problems for the past 22 yr.

Reed Engineering Co. has been serving the national and export market on turning rolls, welding jigs, etc., used in the metal fabricating industry.

J. F. Wagner Honored

J. F. Wagner of Cleveland, Ohio, was elected president of the Independent Oxygen Manufacturers' Assn. at their Annual Meeting held at the Manoir Richelieu in Murray Bay, Quebec, on July 11–13.

In this organization are associated all the independent oxygen producers in the United States, Hawaii and Mexico. This meeting was attended by more than 175 representatives to analyze and discuss industry problems.

Last year at the annual meeting held in Mexico, Mr. Wagner was elected Vice-President of this association and a member of the Board of Directors. He has been very active in the organization since its inception 8 yr. ago.

J. F. Wagner

Mr. Wagner brings a wide fund of knowledge and experience to this newly elected position. He is Vice-President in Charge of Production of The Burdett Oxygen Co. of Cleveland, Inc., one of the largest independent producers of industrial gases in the country. He is also Vice-President of the Burdett Oxygen Co. of California, located in the Los Angeles area and Vice-President of The American Industrial Safety Equipment Co., a subsidiary, located in Brooklyn, N. Y. Mr. Wagner has been associated with The Burdett Oxygen Co., for the past 20 yr. in every branch of their business.

Mr. Wagner is also active in the Compressed Gas Assn., the International Acetylene Assn. and is now Secretary-Treasurer of the Cleveland Section of the AMERICAN WELDING SOCIETY, a position to which he has been re-elected for the past four years.

Changes and Additions to Lincoln Sales Engineering Staff

E. E. Goehringer has assumed sales and engineering responsibility in the Indianapolis area as district manager for The Lincoln Electric Co. Mr. Goehringer has been a district engineer for Lincoln since his graduation from The Ohio State University with a degree of Electrical Engineer in 1935. He has been active in welding development in widely diversified industries in Philadelphia, Boston and Cleveland. The Indianapolis office is located at 3343 Central Ave.

Omer Blodgett has been transferred to the Lincoln Chicago office at 2450 S. Prairie St. Blodgett is a graduate Metallurgical Engineer and has been with Lincoln as an engineer in the Grand Rapids office since 1945. In addition to his duties as a sales engineer, Blodgett has a special assignment in the Chicago area in engineering applications for redesigning to welded-steel fabrication. For this work he is qualified not only by his previous experience with Lincoln but also by his background of 18 yr. in the welding field.

To the Lincoln Pittsburgh office at 22 Wabash St., Pittsburgh, Pa., have been assigned as district engineers R. L. Hall and Robert Hirsch. Hall served in the Army Signal Corps and is a recent graduate of the University of Michigan with a degree in Electrical Engineering. Hirsch graduated from Cornell University as a Mechanical Engineer after serving 2 yr. in the Air Corps, seeing action in the E.T.O. as a 1st Lieutenant.

Air Reduction Personnel Changes

J. B. Davenport, formerly assistant manager of the Detroit district, has been appointed assistant manager of the Charlotte district of the Air Reduction Sales Co.

J. H. Hart, formerly assistant sales manager at Detroit, has been promoted to assistant manager of the district. R. A. Jamieson succeeds Mr. Hart in Detroit.

A. S. Blodget, Jr., has been appointed assistant manager of the Boston district.

Employment Service Bulletin

Position Vacant

V-238. Welding Engineer wanted. Desirable to have Metallurgy degree or equivalent with several years' experience welding high-temperature alloys. Employment contingent upon security clearance.

Service Available

A-582. Resistance Welding Engineer desires position in either manufacturing or research location immaterial. Electrical Engineer, 9 years' experience on production, design, research, electronic controlled circuits and maintenance; manual and automatic arc welding, inert gas, stud and all types of resistance welding. Further details sent on request.

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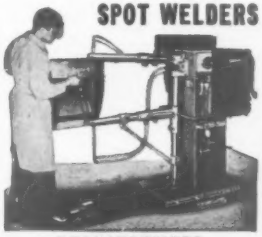

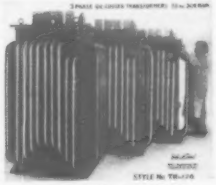

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NEW PRODUCTS

Projection Weld Nut

The new type Gripco "Pilot" projection weld nut is designed for easy, quick positioning or centering at the spot where it is to be welded to the metal. A circular "collar" with a diameter slightly less than the bolt hole is provided on the weld nut. The workman inserts the collar of the Gripco pilot weld nut into the bolt hole (with one hand) and that automatically centers the nut accurately, ready for the welding operation. There is no need for jigs, no fumbling, no measuring, no time wasted.

Gripco weld nuts are used where application is difficult, due to restricted space or where metal sections are too thin to thread. The application process is reversed, the nuts being welded into final position and the bolt screwed into the nut. Weld nuts are also attached to various bulky or heavy products, so they can be bolted securely against shifting in transit.

Gripco pilot weld nuts are furnished with common nut threads, or with the Gripco double-triangle thread-locking feature, which locks the bolt to the nut.

Gripco pilot weld nuts are manufactured in their entirety by the Grip Nut Co., 307-K, S. Michigan, Chicago 4, Ill.

New Slope Control for Resistance Welding Machines

A new slope control for use as an accessory with either synchronous or nonsynchronous resistance welding machines of the single-phase type, has been announced by General Electric's Control Divisions.

Designed to provide the desirable refinement of a gradual increase in welding current at the beginning of the weld, the new control materially reduces tip pickup in spot welding aluminum, magnesium and their various allloys. Consequently, more welds can be made before the electrodes must be redressed. Laboratory tests with this control resulted in obtaining 20 times the number of spot welds on 0.064-in. 24ST Alclad aluminum, before sticking occurred, than were obtained without the control. The control is also desirable for welding heavy-gage steel and for projection welding, since it minimizes expulsion.

The new accessory control is furnished in two types: one intended for mounting in the side of synchronous controls, the other—in a separate enclosure—for use with older types of control and nonsynchronous control. The operator's panel consists of two dials and a transfer switch. The setting of one dial, which is graduated from 3 to 13 cycles in one-cycle steps, determines the time for the welding current to reach a final value from its initially low

one. The other dial, graduated in per cent of the final current, permits adjustment of the initial value of the welding current. The transfer switch facilitates disconnecting the slope control for those operations for which it is not needed.

In operation, the slope control functions as a variable resistor placed in series with the heat-control rheostat in the standard welding control panel. The value of this resistor varies with time. At the beginning of weld time, a control relay in the slope control is energized. Operation of this relay starts an electronic timing circuit, causing the "resistor" to vary in value. By this means, the phase of the heat control in the main panel is gradually advanced. Consequently, the welding current is increased gradually from the initial value selected to the final value of current set on the heat-control dial of the standard panel.

Fluxes

Two new fluxes with highly desirable features have been developed and added to its regular line of fluxes, according to a recent announcement by the Superior Flux Co., of Cleveland, Ohio.

First is the Number 66 Silver Solder Paste Flux. Its outstanding advantage is its extremely low melting point, 650° F., and liquefaction is constant to 1650° F. The very low melting point causes the flux to wet and clean the metal faster. Other features are the low viscosity and excellent capillary action.

The second flux is Number 77 Soft Solder Paste Flux for use in soldering steel, silver, copper, brass, various alloys and electroplated parts. It has the same properties as Superior Number 30 Liquid Flux, but is now furnished in paste form for particular applications. Because of the low melting point, it has a high wetting action. This flux will not leave any acid or gummy residue or create noxious fumes. Its important advantage is that its action is noncorrosive and the residues are completely soluble in water.

For literature regarding these products write to Superior Mfg. Co., Dept. WJ-8, 1302 Ontario St., Cleveland 13, Ohio.

Superfast New Electrode

Eutec-Hand-Omatic is an a.-c., d.-c., no-gap electrode. It is merely pressed against the metal and drawn straight along, like a pencil, without any back-and-forth or weaving motion. A perfect weld results automatically and since there is no arc gap maintained, the ease of operation is readily apparent.

Another factor in fatigue is the constant watchfulness demanded in order to avoid burning through when welding light-gage steels. With Eutec-Hand-Omatic, thin sheet can be welded with a negligible risk of burning through. And along with its high speed of welding, a saving of up to 50% in electrode material is obtained.

Eutec-Hand-Omatic gives superb results on all mild steels and on the low alloys, high-tensile steels now used extensively by railroads, truck and trailer manufacturers, etc. It needs no special equipment. It exhibits its superior qualities in straight production work in shops and plants fabricating thin-sheet components such as cabinets, housings, vending machines, grain elevator equipment, machinery guards, truck, trailer and bus parts, farm implements, etc. Business conditions compel the closest attention to reduction of costs, and Eutec-Hand-Omatic is outstandingly in line with this economic trend.

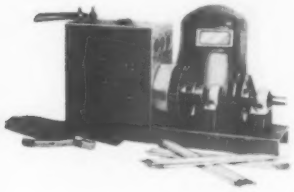
For use with both a. c. and d. c. Eutec-Hand-Omatic has a tensile strength of 70,000-80,000 psi. and is available as follows: No. 1 in $^{3}/_{32}$, $^{1}/_{8}$ and $^{5}/_{32}$ in. No.

II and No. III in $^1/_8$ and $^6/_{32}$ in. For further information write to Eutectic Welding Alloys Corp., 40 Worth St., New York 13, N. Y.

Arc Welder

The new Model 202 arc welder which is designed for any welding job, light or heavy, has recently been placed on the market by the Manufacturing Div., Groban Supply Co., 1507 S. Michigan Ave., Chicago 5, Ill.

The new arc welder has a continuous welding rating of 200 amp., intermittent rating of 250 amp.



It is an excellent buy for farmers, factories, machine shops, home work shops, servicemen, repairmen, ship yards, construction work, contractors—in fact, wherever welding is needed.

The Model 202 arc welder is designed for years of trouble-free service. It handles anything from light-gage sheet metal to $^1/_4$-in. plate. This precision-engineered arc welder can be mounted permanently or easily transported for portable use. It does the job where and when needed.

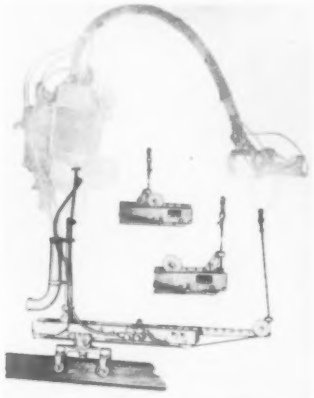
Run welder at 2500 rpm. from drive pulley of tractor or a $7^1/_2$-hp. electric motor or a 10-hp. gas engine. Use one or two V-belts (on pulley). The shipping weight is 95 lb. The remarkable low price of this excellent arc welder is only $99.50 F.O.B. Chicago.

An accessory kit, including welding helmet, electrode holder, two 10-ft. cables with clamp and 5 lb. of assorted welding rods, is available for only $10.50 F.O.B. Chicago.

For urther information, write Groban Supply Co., at the above address.

Portable Welder Gun Balancer and Hanger

The portable welder gun balancer and hanger balances a welding gun in any position in the balancing range without any up or down creep, and can be moved up or down with the slighest pressure. The operator is free to spot weld any operation without drudgery, whether in an up or down, right or left movement or stationary, it is ideal for conveyor line spot welding.



This is a complete unit with trolley and operates on a 4-in. standard I-beam. (Furnished to operate on a Cleveland Tram-rail or American Mono-rail as extra equipment.) The hanger has a transformer adjustable mounting bracket, adjustable from $1^1/_2$ to 9 in. off center of main supporting bracket for counterbalancing overhanging weight of welding gun and cables. A swivel conduit tube is provided which holds the input and exhaust water hose, control wires, power wires to transformer and air or hydraulic hose to welding gun. The complete hanger revolves 360°, has adjustable welding gun extension or support arm allowing welding gun adjustment of 21 to 60 in. from transformer. It is also provided with a safety latch which holds the balanced load at the top of the balancing range when production line is down for the day. This safety latch holds the load suspended out of the path of the conveyor line when the air-line pressure is shut off. When the air is again turned on, the latch is released by a convenient control knob.

The Platz Co., Inc., 20433 Sherwood Ave., Detroit 34, Mich.

A.-C., D.-C. Electrode

A new a.-c., d.-c. electrode combines great resistance to corrosion with a tensile strength of 110,000–120,000 psi. as-welded (work-hardenable to 180,000 psi.) and is now available through distributors of All-State Welding Alloys Co., Inc., 273 Ferris Ave., White Plains, N. Y. In exhaustive field tests this electrode has turned in a brilliant performance on the new, special-type high chromium-nickel steels, as well as very high-alloy steels, tool steels and die steels.

The new electrode, identified as All-State No. 299 is especially recommended for the welding of vanadium-moly spring steels, nickel-clad steels, medium-carbon steels and air-hardenable steels. The wide range of its applications already includes many high-specification jobs such as pressure vessels, jet-propulsion equipment, tools and dies.

Preheating the base metal to a temperature of 300–500° F. is good practice. The deposited metal cannot be heat treated.

Heavy-Duty Arc Welder

Air Reduction, manufacturers of industrial gases and welding equipment announces the immediate availability of a new heavy-duty arc welder. Known as the Wilson 36A "Yellow Jacket," this machine is built in 300- and 400-amp. sizes. According to Airco, the Yellow Jacket is especially suitable for pipe-line work, construction jobs or any work where ruggedness and durability are important factors.

The Yellow Jacket is a direct current, 40-v., N.E.M.A. approved, variable voltage generator. It features simplified control of current output by means of a sturdy handwheel mounted on the control cabinet. Close calibration of the current dial eliminates the need for meters.

For instant recovery voltage over short

WELDING CONNECTORS
Saxe System Welded Connection Units
for welded assembly

Saxe Units place in position and securely hold together structural parts to be welded.

As used in many welded structures they *eliminate all hole punching* producing an economical, rigid, safe and quickly erected structural frame.

"Write for 58 pg. Manual containing full engineering design information for welded structures."

J. H. Williams & Company
Buffalo 7, New York

G. D. Peters Company
Montreal 2, Canada
Canadian Representative

FOR SALE

Progressive battery operated press type projection welder, complete with bus connections to power pack. Has retractable stroke. 16 cell, 8 volt power pack with contactor and heat regulator for use with above. 1000 ampere, 8 volt charger unit with charge regulator, charge control, weld and sequence timer, including squeeze, weld, hold, and off time. For operation on 220–240, 60 cycle, 3 phase current. (Compares with 100 KVA capacity.) Also have 20 KW 220–240 volt 3 phase generator direct connected to Hercules diesel engine for operation of same. Machine is set up for operation and in good condition. Open to offer. Electric Soldering Iron Co., Inc., Deep River, Conn.

Outstanding Development of A.O. Smith Welding Research

A.O.Smith

Certified

AC-DC MILD STEEL ELECTRODE

NEW SW-17

The most important basic contribution to mild steel welding since the introduction of SW-15

A.O. Smith welding research has given the new SW-17 Electrode three outstanding characteristics never before combined for Class E-6012 users:

★ EXCEPTIONALLY HIGH IMPACT RESISTANCE . . . retained at temperatures as low as minus 40° F. or lower.

★ HIGH WELDING CURRENTS as much as 25% higher current settings are possible without affecting welding quality or appearance.

★ INCREASED DUCTILITY . . . 25% to 32% elongation in all-weld tensile test specimen.

SW-17 has been developed by A.O. Smith specially for fabrication, maintenance, and repair of machinery and road equipment . . . and for *all* heavy-duty applications where extreme toughness and high impact strength are required to withstand severe operating and temperature conditions.

Physical properties are outstanding: Ductility and notch toughness of deposit metal far exceed Class E-6012 requirements. Resistance to impact, at critical sub-zero temperatures, *surpasses results heretofore achieved in mild-steel welding.*

SEND FOR INFORMATION ON THE NEW SW-17

A. O. SMITH Corp., Dept. WJ-949, Milwaukee 1, Wis.

Without obligation, send us

- ☐ Information on the SW-17 Electrodes
- ☐ A. O. Smith Electrode Catalog
- ☐ Bulletins on A. O. Smith AC Welders

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Firm _____

Street _____

City _____ State _____

A.O.Smith

CERTIFIED WELDING ELECTRODES

75th ANNIVERSARY 1874 - 1949

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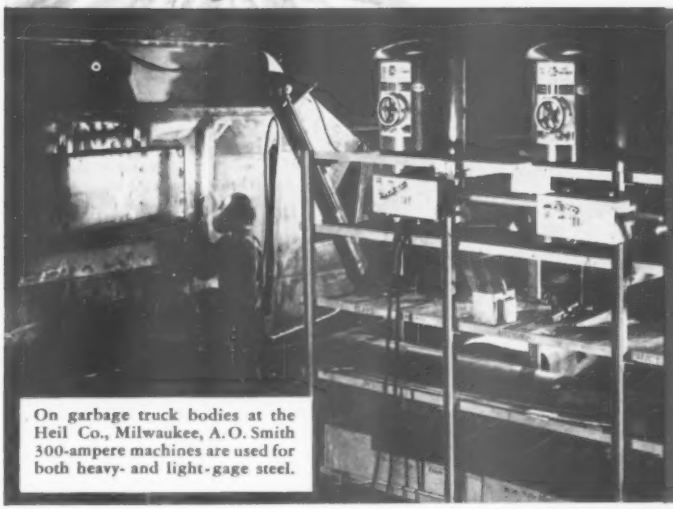
Pittsburgh 19 • Atlanta 3
Chicago 4 • Tulsa 3 • Dallas 1
Midland 5, Texas • Houston 2
Seattle 1 • San Francisco 4
Los Angeles 14
International Division: Milwaukee 1

Here Are Cost Savings You Cannot Afford to Overlook!



On garbage truck bodies at the Heil Co., Milwaukee, A. O. Smith 300-ampere machines are used for both heavy- and light-gage steel.

A.O.Smith HEAVY-DUTY AC WELDERS

In almost every case, where A. O. Smith AC Welders have replaced DC motor-generator installations, they have consistently saved enough to *more than pay for themselves in one year* . . . on power cost alone.

The cost of idle-time power, to keep rotating parts in motion is saved. This economy, plus the improved efficiency under load of the AC transformer-type machine, results in power savings you'll want to investigate.

In addition, A. O. Smith AC Welders eliminate arc blow, permit the use of larger electrodes and faster welding speeds. An annual air-blast cleaning is the only maintenance required.

In both new and replacement jobs, installation costs less. A. O. Smith Welders have been shop-proved on our own production lines, producing thousands of welded steel products every working day.

Ask one of our engineers to call and show you proof of performance, and proof of lower costs, by computing AC Welding savings in advance. Write on your letterhead or send the coupon for detailed literature.

Made by Welders • • • for Welders • Sold by Distributors Everywhere

A.O.Smith
AC WELDING MACHINES

A. O. Smith 75th Anniversary 1874 1949

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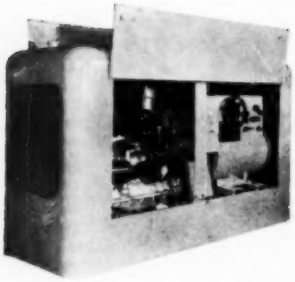
Pittsburgh 19 • Atlanta 3
Chicago 4 • Tulsa 3
Midland 5, Texas • Dallas 1
Houston 2 • San Francisco 4
Seattle 1 • Los Angeles 14
International Division: Milwaukee 1

SEND FOR THESE FREE BULLETINS

A. O. Smith Corp., Dept. WJ-949, Milwaukee 1, Wis.
Without obligation, send us complete information on:

- ☐ A. O. Smith Heavy-Duty AC Welders
- ☐ A. O. Smith Limited Input Utility Welder
- ☐ A. O. Smith General-Purpose AC Welders
- ☐ A. O. Smith Certified Electrode Catalog

Name _____
Firm _____
Street _____
City _____ State _____



circuit, the 36A generator is self-excited with excitation of the main field obtained through an auxiliary brush.

Welding terminals are conveniently located and adequately spaced to prevent accidental shorting between the lugs of the welding cables.

The Yellow Jacket 36A is a complete two-bearing unit, engine driven by sheaves and steel-cored V-belts. The belt drive reduces vibration problems in the field by automatically compensating for slight misalignments. Precision ball bearings equipped with double shields keep dirt out and hold grease in providing maximum load safety.

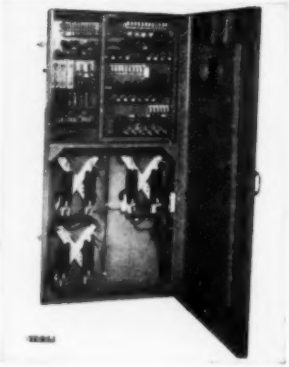
The 36A is powered by a sturdy six-cylinder industrial engine and is available in stationary or portable models. It is 76 in. long, 28 in. wide and 49 in. high.

Optional equipment includes either a two- or four-wheel, high-speed, spring-mounted trailer equipped with pneumatic tires for use with the portable model.

For further information on this machine, write Air Reduction, 60 E. 42nd St., New York 17, N. Y., or the Airco sales office or authorized dealer nearest you.

Three-Phase, Low-Frequency Resistance Welding Control

A new three-phase, low-frequency welding control, designed to operate a welding transformer so as to draw power from a three-phase line and convert it to a lower frequency single phase and supply this



to the electrodes of a resistance welder, is available from Westinghouse Electric Corp.

High-power-factor characteristics inherent with low-frequency current result in reduced kva. demand for any given number of amperes at the electrodes. The total power demand is spread over all phases of any standard three-phase, 60-cycle, 220-, 440- or 550-v. primary power source.

Weld quality is better because the wave shape obtained with three-phase control allows for a smooth flow of heat into the metal.

A complete packaged unit that controls all mechanical and electrical functions of the welding machine is available. It can be mounted on the floor or on the side of the machine. A swing-out panel provides easy access to all components and circuits.

For further information, write Westinghouse Electric Corp., P. O. Box 868, Pittsburgh 30, Pa.

Square D Electronic Heat Controls now in Separate Enclosures

New electronic heat controls for spot and projection welders are now available in separate enclosures, through the Square D Co. Styling and dimensions of enclosures match electronic contactors or nonsynchronous electronic timer-contactor combination controls. Class 8990

Have you a metal-cleaning "tough nut"

. . . to crack?

Is it the removal of:

- oils or greases?
- pigmented drawing compounds?
- carbon smuts?
- lime scale or mill scale?
- soldering flux?
- tarnish or rust?
- rust preventives?

Or is it preparation for:

- welding?
- galvanizing?
- porcelain enameling?
- anodizing?
- painting?

FREE When these things bother you, remember that there is no charge for Oakite advisory service on any metal-cleaning job. Just write to Oakite Products, Inc., 18E Thames St., New York 6, N. Y.

OAKITE 1909 1949 40 ANNIVERSARY YEAR

OAKITE

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Technical Service Representatives Located in Principal Cities of United States and Canada

COMPLETE CARBON BRUSH DATA

SPECIFICATIONS FOR ALL MAKES AND TYPES OF WELDING EQUIPMENT

yours for the asking

Twenty-eight pages of easily found information, complete with factory model numbers, replacement brush numbers, scaled illustrations of brushes listed, and all other necessary data. Here is a regular "Encyclopedia" of Brush information covering all types and makes of welding equipment.

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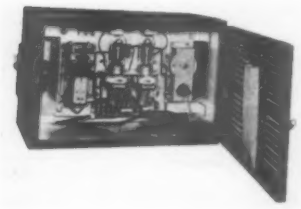
B·B·B Stands for Quality . . . EVERYTHING IN CARBON

BECKER BROTHERS CARBON CO.

3450 SOUTH 52nd. AVE. CICERO 50, ILL.

heat controls provide stepless adjustment of welding current from 20 to 100% on 440-v. systems, or from 40 to 110% on 220-v. systems.



The new design emphasizes a number of features important to industrial users. For maximum ease of servicing and maintenance, all components and circuit tie points are brought to terminals which are completely accessible simply by opening the enclosure door.

Tubes, warm-up timing relay and all circuit components excepting a large capacitor and transformers are plainly visible when the enclosure door is opened. Disconnect plugs and $^1/_4$-turn fasteners enable the user to quickly remove the complete panel and power supply in one piece, without disturbing external connections. Soldered connections are eliminated, and only a screwdriver and pliers are needed to replace components.

The adjuster dial is covered by a small door which can be locked to eliminate tampering. This construction protects the operator while making adjustments, since he does not open the main door to electrically live parts. Choice of ignitor firing tubes gives warm-up time of less than 1 min.

Controls can be provided with an enclosed auxiliary heat adjuster and a transfer switch which permits selection of either dial setting from a remote location. For remote control from a single location, the adjuster rheostat may be removed from the control and separately mounted.

For further information, write Square D Co., 4041 N. Richards St., Milwaukee 12, Wis.

Sequence Weld-Timer

A new design of the Westinghouse N.E.M.A. 3B Sequence Weld-Timer permits faster consistent operation and more accurate sequence timing for nonsynchronous resistance welders. It also provides easy low-range adjustment.

The redesigned N.E.M.A. 3B timer is enclosed in a wall-mounted sheet steel enclosure. The interior (control) panel, with plug-in subassembly construction, is arranged to swing out in a horizontal plane to permit ease of servicing. Time setting dials are arranged for ease of time selection. Rapid acting relays operate with a minimum time delay to guarantee more accurate timing.

The new N.E.M.A. 3B timer is designed for operations up to 450 spots per minute on 20-gage steel.

For further information, write Westinghouse Electric Corp., P. O. Box 868, Pittsburgh 30, Pa.

World's Largest Oxyacetylene Cutting Blowpipe

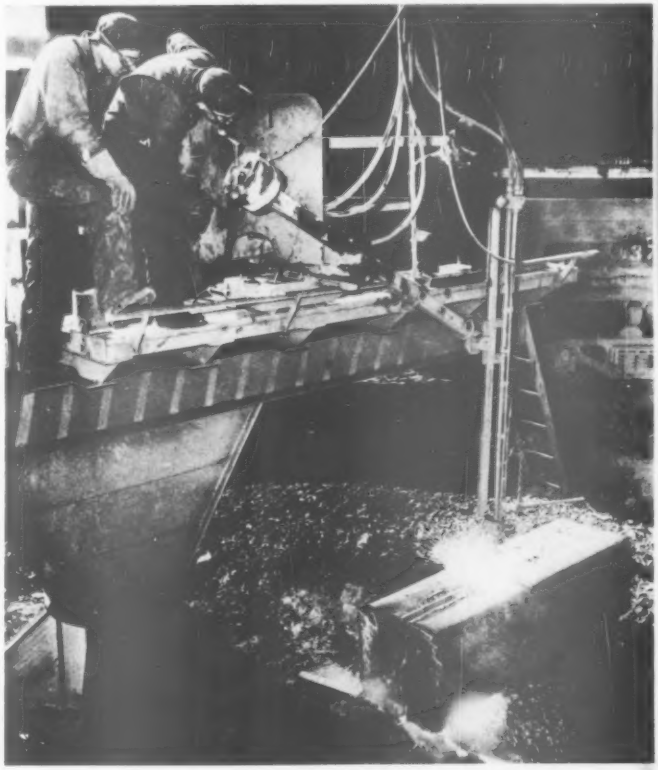
Novel features of the scrap-cutting setup at the Colorado Fuel and Iron Corp.'s Pueblo, Colo., plant are shown in the accompanying illustration. The Oxweld C-60, the world's largest cutting blowpipe is mounted on a turntable unit and traversing carriage. Thus, the blowpipe is accessible to work in a wide area. A counterweight makes easy the raising and lowering of the blowpipe.

As pictured, the C-60 blowpipe is cutting lengthwise through an ingot 2 ft. thick at a rate of 3 in. per minute. Metallurgists at Colorado Fuel and Iron state that with the installation of the new blowpipe, greatly increased studies of ingots will now be possible.

Although the new blowpipe will have varied uses for test purposes, its primary function at Pueblo, however, will be for cutting buttons and skulls. Heretofore, large buttons could not be reclaimed economically as scrap for use in the open-hearth furnace. Therefore, a large cutting blowpipe was needed in the slag yard which could reduce large buttons to charging-box size. The Oxweld C-60 blowpipe is a product of The Linde Air Products Co., a Unit of Union Carbide and Carbon Corp.

This blowpipe has been specially designed for extra-heavy cutting operations, such as the scrap-cutting of skulls and buttons. Continuous cuts through steel 68 in. thick have been made at Pueblo. This blowpipe, using the powder-cutting principle, is particularly well suited to cutting scrap having more than a normal amount of cinder and slag inclusions.

In the powder-cutting process an iron-rich powder is blown into the oxygen stream from outside the preheat flame. Powder is heated to ignition temperature by the oxyacetylene preheat flame. Refractory oxides are removed continuously by a melting and fluxing action as the cutting proceeds. By this process, materials oxidation-resistant to the normal oxyacetylene flames are easily cut at speeds comparable to cutting equivalent thicknesses of carbon steels.



Time-tested, performance-proved!

REGO*

Rego KX Hand Cutting Torches and NCG's Cut-O-Matic and RS Cutting Machines speed production at Welded Steel Shapes, Inc., structural steel fabricators at Coatesville, Pa. NCG's pipe-line system, fed from portable banks, keeps NCG gases flowing conveniently and economically at this modern shop where work ranges from the fabrication of buildings and bridges to farm equipment.

Rego welding and cutting apparatus is used at Detroit's Wolverine School of Trade where for 20 years men have been expertly trained in general welding and automobile mechanics and body work. Last year Wolverine graduated 2100 students. Wolverine, source of thousands of skilled workers for the motor industry, uses NCG gases

*T. M. of The B. B. Co., Chicago

For the past 15 years NCG gases and Rego flame-cutting and welding apparatus have been used in the plant maintenance program of Standard Steel Spring Co., Coraopolis, Pa., manufacturers of automobile springs and bumpers. In the picture above the maintenance crew is seen at work at Standard's No. 2 plant at Coraopolis. Standard has other plants at New Castle, Pa.; Newton Falls, Ohio; Allegan, Mich.; and Gary and Logansport, Indiana.

You, too, can save hours and dollars with efficient, dependable REGO apparatus

NCG

EVERYTHING FOR WELDING

NCG is recognized as one of the largest organizations of its kind in the world. It operates 73 manufacturing plants within the United States, offers supply and service by a vast network of hundreds of authorized NCG dealers and warehouses. For assured satisfaction in *your* welding and cutting needs . . .

RELY ON NCG

Accuracy has long been an outstanding characteristic of Rego Oxy-Acetylene Cutting and Welding Apparatus—and when you couple accuracy with efficiency, dependability and economy—you have a combination that can't be beat . . . Why don't *you* see if thoroughbred Rego equipment doesn't help *you* save gas, do better work, speed production—as it has for *thousands* of others? Rego is a pioneer line, tested by time, backed by 30 years of leadership!

NATIONAL CYLINDER GAS COMPANY

Executive Offices:

840 N. Michigan Avenue, Chicago 11, Illinois

Copr. 1949, National Cylinder Gas Co.

New Etching Process

A revolutionary new etching process to prepare metal surfaces for microscopic examination and photography has been developed by the Ford Motor Co.

The unique metal-etching method—never before used in industry—utilizes ionized atoms. The process is known as cathodic vacuum etching.

Etching is widely used in industry to examine metal structures for determining quality and aiding in development of new materials or manufacturing processes.

Cathodic vacuum etching has brought an important improvement. It enables the taking of an unusually clear photograph of flow lines—a curious strata-like pattern which indicates the direction the metal flowed when forged under high pressure.

The new etching technique works this way: The metal sample is placed in a partial vacuum with argon, a rare gas found in the air. Twelve thousand volts of electricity are charged into the vacuum, creating argon ions which bombard the metal surface and knock off minute particles.

Under the newly developed method the physical features of metal can be examined under a microscope and measured accurately as to their effect on strength and performance in whatever part of the Ford cars the metal ultimately will become a fixture.

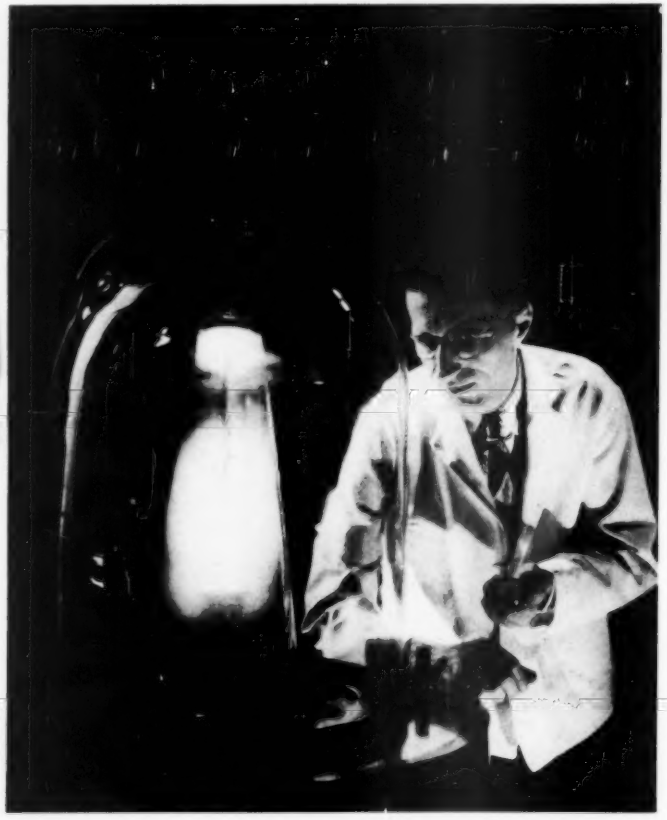
Flow lines in steel samples previously undetected now have been revealed by cathodic bombardment.

Comparison of the structure pattern produced by the best chemical etching method revealed that the new cathodic treatment brings out the true microstructure of the metal with greater detail and clarity.

A special pressure-rolled Ford front wheel spindle was examined experimentally by the usual microscopic technique. No superficial layer of flowed metal could be detected by the chemical-etching process. However, cathodic-bombardment etching revealed the entire superficially rolled structure, showing individual flow lines which indicated that deformation was only 0.005 in. deep.

Results also were obtained which indicate that grain structure of metals also can be more clearly shown by cathodic bombardment. Ford engineers have begun an extensive program to explore this phase of cathodic etching.

Photographs illustrating cathodic-etched structures were awarded first prize in an exhibition sponsored by the American Society for Metals.



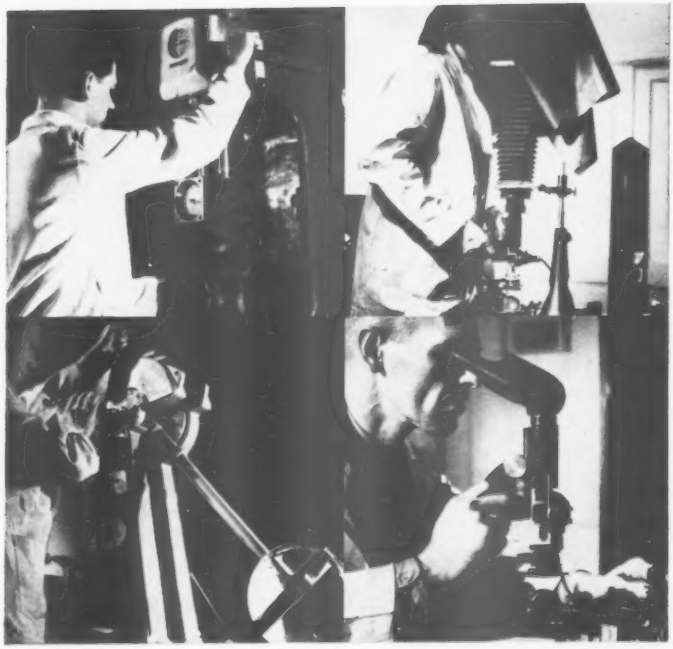
A metal sample being tested by Don M. McCutcheon, of the Ford Motor Co.'s applied physics research department

200-Amp. Arc Welder

Air Reduction, manufacturers of industrial gases and welding equipment, has announced the immediate availability of a new a.-c. transformer arc-welding machine, known as the Wilson 200-Amp. Max. MCT. According to the manufacturer, this economical, portable welder was specifically designed for use by small shops, garages and maintenance crews. It has a rated maximum output of 200 amp., is completely self-contained and offers the following features:

1. Welding range is divided into two ranges of current adjustment with stepless control throughout each range.
2. Capacitors are supplied in the secondary circuit to provide easy arc starting and arc stability.
3. Built-in capacitors in the primary circuit provide power factor correction.
4. Any desired setting can be made quickly and accurately by simply turning the crank handle on top of the machine.
5. Full-view scale makes current settings easy to read.
6. Windings are fully insulated with heat-resistant spun-glass fiber.
7. A primary "on-and-off" switch and a 10-ft. length of three-conductor rubber-covered primary cable with lugs attached are included with the machine.

For complete details on this newest edition to the Airco arc-welding line, write the Airco office or authorized dealer nearest you.



Raw material control means better Tube-Turn welding fittings

What's a piece of steel made of?

THE quality of a finished product is largely dependent on the quality of the raw material from which it is made. That's why Tube Turns' laboratory technicians thoroughly test every lot of seamless steel tubing received in the Tube Turns, Inc. plant.

Answers to that important question —*What's a piece of steel made of?*— are determined in two ways. First, by chemical tests that disclose the exact percentage of the various elements present in the steel. And, second, by physical tests to determine the steel's tensile strength, yield strength, and elongation. Unless the steel measures up in all respects, the entire lot is rejected.

At the end of these tests, not only is the chemical composition of the steel known, but an accurate appraisal of its metallurgical and physical characteristics has been made. And these facts are filed by the laboratory control number rolled into each fitting to identify it permanently with the lot of steel from which it was made.

This rigid control over raw material is your assurance of basic quality in the Tube-Turn welding fittings you buy. Modern equipment in the hands of skilled technicians permit only the best steel to be used for the manufacture of Tube-Turn products.

Remember, you can always bank on good service in good connections every time you specify "Tube-Turn."

TUBE TURNS, INC.

222 East Broadway, Dept. J, Louisville 1, Kentucky

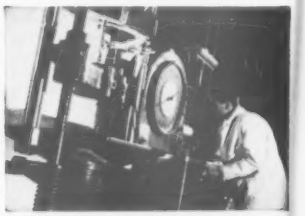
District Offices at New York, Philadelphia, Pittsburgh, Chicago, Houston, Tulsa, San Francisco, Los Angeles

TUBE-TURN

tt

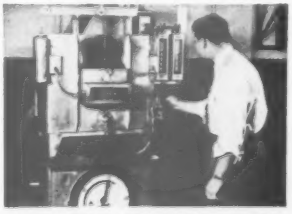
WELDING FITTINGS AND FLANGES

Foolproof chemical analysis of steel is made quickly and accurately on this Spectroscope, typical of the modern equipment used by Tube Turns, Inc. in the control of raw material.



Tensile strength of all seamless steel tubing is accurately measured on this machine, capable of exerting a force of 60,000 pounds. Yield strength and ductility are also checked here.

Periodic checks on the hardness of the steel are made with this Rockwell instrument to determine the strength, ductility, and machinability of the material. Brinell equipment is also used to check hardness.



Advance indication of what will happen to the steel during processing is determined with this electric furnace, one of a battery. Heat treatment to which the material will be subjected is duplicated here.

Flat Thermometer

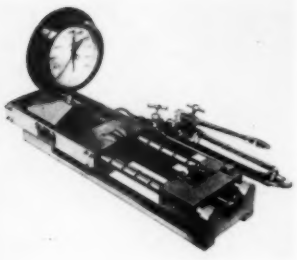
The new Dillon flat-stem magnetic thermometer can be used in dozens of applications where heat must be indicated, but conventional round-stem instruments just cannot do the job because of their shape.

For example, items such as electric flat irons, griddles, transformers, engine blocks, air ducts, exhaust ports, etc., can be checked with this device. The large flat area quickly gathers and retains heat from the surface under test. It actually covers the heat area like a blanket whereas round-stem units would permit the heat to escape past them around each side of the stem.

The magnets enable the operator to place the thermometer on a flat surface and "peel" if off in an instant; thus saving untold time usually required for fittings of a more complicated nature.

Field Testing Machine

Announcement is made by Steel City Testing Machines, Inc., Detroit, Mich., of a new, portable tensile-testing machine for making field tests where conventional testing equipment is not available. Known as Model PO-40 Portable Tensile Tester, this machine is particularly adapted for testing pipe welds and other types of welds where on-the-job testing is preferable. Its use, however, is not limited to field testing, as its high degree of accuracy makes it satisfactory both for laboratory and for shop testing.



The capacity of this machine is 40,000 lb. and it will make tests on specimens from 6 to 13 in. in length and up to $^{3}/_{8}$ in. thick and $2^{1}/_{4}$ in. wide. Its operation is hydraulic, by means of a hand pump integral with base. This machine is easily adjustable and is light enough (slightly over 200 lb.) to be carried by two men. Model PO-40 is furnished complete with pump (which contains its own oil reservoir) easy-to-read dial gage, and one set of flat jaws. It is shipped completely assembled, ready for immediate use.

Literature outlining complete specifications is available from Steel City Testing Machines, Inc., 8843 Livernois, Detroit 4, Mich.

Stud Welding Aluminum Industrial Roofing

The Reynolds Metals Co. has adopted the Nelson electric-arc stud-welding method for attaching 0.032-in. industrial corrugated aluminum roofing and siding direct to structural steel framing members, it was announced today by W. G. Reynolds, Vice-President and Manager of Reynolds Building Products Division and L. C. Barr, Vice-President and General Sales Manager, Nelson Stud Welding Division, Morton Gregory Corp.

LIST OF NEW MEMBERS

July 1 to July 31, 1949

ATLANTA

Young, C. A., Jr. (C)

BOSTON

Clemmey, John L., Jr. (B)
Hughes, Leonard J. (B)

CHATTANOOGA

Bryan, James A. (C)

CHICAGO

Barthelemy, C. R. (B)
Montania, Elmer C. (C)
Munse, William H. (C)

CLEVELAND

Judge, Lee (B)

COLORADO

Preston, William Jordan (B)

DALLAS

Goforth, James (C)
Humes, Perry A. (C)
Quillen, Fred M. (B)

DETROIT

Duffy, W. Henry (C)*
Woodrow, Kenneth C. (C)*

INDIANA

Williams, David G. (B)

LONG BEACH

Markham, M. G. (C)
Tresoti, Paul M. (C)

LOS ANGELES

Duff, James G., Jr. (B)

MAHONING VALLEY

Allardt, E. W. (C)
Cross, C. W., Jr. (C)
Hinst, H. F. (C)
Rearick, G. H. (C)

NEW JERSEY

Baron, Mike (B)
Coupe, Ralph (C)
Gallagher, Charles (C)
Glacklin, Thomas (B)
Jarolema, William (B)
LaMedica, Mike (B)
Radkovich, Leon (B)
Reilly, James (B)
Russo, Palmer (C)
Simms, Forde (B)
Smith, William F. (A)
Sytch, Gregory G., Jr. (C)
Traynor, John E. (C)

NEW YORK

McClure, Charles A. (C)
McWaters, Raymond J. (B)

NORTHERN NEW YORK

Molenaar, Charles R. (C)

OKLAHOMA CITY

Bishop, J. O. C)
Clavert, Foster (C)
Dawes, S. B. (C)
Johnson, Walter G. (C)
Williams, James A. (C)
Wormstaff, W. M. (C)

PHILADELPHIA

Fliszar, Julius F. (C)

PITTSBURGH

Emmanuel, G. N. (C)
Olzak, Z. E. (C)
Rutherford, John J. B. (C)

ROANOKE

Adkins, B. H. (C)

SAN FRANCISCO

Thompson, Theodore J. (C)

WESTERN MICHIGAN

DeYoung, Harold (C)

NOT IN SECTIONS

Anderson, James L. (B)
Bartlett, Charles B. (B)
Hawley, W. G. (C)
Kennedy, Blair (C)
Maples, L. E. (C)
Rust, Frank P. (B)

Members Reclassified

During month of July

TULSA

Douglas, Lester (C to B)

NOT IN SECTION

Ashton, G. E. (C to B)

* Above members previously omitted.

SECTION ACTIVITIES

Report of Activities of the Mid-Southern District

***Editorial Note:** Taking advantage of a mid-summer lull in reports from the Sections, the Journal is devoting this space normally occupied by Section Activities to a report from Ray Townsend, District No. 6 Vice-President, Mid-Southern District*

Extracts from Letter Dated July 25th

Mr. J. G. Magrath, Exec. Sec.,
American Welding Society,
33 W. 39th St.,
New York 18, N. Y.

RE: Mid-Southern District Report

Dear Joe:

In complying with the requirement that the District Vice-President give an annual report on his Sections I am attaching herewith minutes of the annual meeting held in Houston at the Ben Milam Hotel on July 16th with all Sections represented and reporting.

You will find in the minutes of the annual meeting answers to several of the questions you suggested be discussed at this meeting.

It was brought out in the annual meeting that Mid-Southern had a gain of 58 members for the year, which included the membership of the new Dallas Section—accounting for 60 members. This was a gain of 9½% which would have actually represented a loss if the Dallas Section had not been organized. The District at this time has a 6½% delinquency record. Twenty-one per cent of our membership fell by the wayside during the past year—160 new members being signed up, with 127 lost, gives our present membership almost a 24% "new blood injection" during the year.

All Sections with the possible exception of Denver within the District appear to be functioning normally with varying degrees of success as reported by their delegates. There appears to be somewhat of a feeling that each Section should develop locally more of its programs rather than always being dependent on an imported speaker. Practically all Sections felt that the increased dues had an effect on their membership renewals. There was favorable comment on the "cleaning up" or maybe it should be "cleaning down" of the JOURNAL.

The District Vice-President has prepared a District Roster giving the names of all officers, their company affiliation, mailing address and telephone numbers. This is being circulated throughout the District to facilitate easy communication between Sections. This is a time saver throughout the year.

The annual meeting was voted very much a success. Time was very crowded. It could have been made a two-day affair very easily and more could have been accomplished, however it is thought that attendance is perhaps better for the one day on a week end as many delegates cannot get away for a longer period of time. The Houston Section, our host this year, did a most excellent job of lining up the entire meeting down to the *n*th degree. Nothing was missing. The Boat Trip down the Industrial Canal to the San Jacinto Monument and the Battleship Texas on the cutter Sam Houston was a treat and a highlight of the entertainment provided.

If all districts of A.W.S. could have an annual meeting of the Section Officers it would do something for A.W.S. that today does not exist. With our district having a 100% representation and distances of up to 1100 miles involved from Denver to Houston, it would appear that Headquarters should encourage and promote such activity in the other Districts.

Sincerely yours,

R. L. TOWNSEND
Dist. Vice-Pres.
Mid-Southern No. 6

Minutes of Annual Meeting

Ben Milam Hotel, Houston, Tex., July 16, 1949

Presiding: R. L. Townsend, District Vice-President.

Delegates in attendance. Dallas Sec-

Meeting Mid-Southern District Group

tion—John A. Wilson; Colorado Section—C. B. Swift; Kansas City Section—Sam Walker, E. D. Anderson, Joe Payne; Oklahoma City Section—Bill Brewer, James Dawson, John Dwyer, M. J. Barnes; South Texas Section—H. V. Mosby, Allan Wisler, P. D. Morgan, Bill Greer, Bill Hickman, Larry Megow; St. Louis Section—J. H. Weigel; Tulsa Section—J. B. Davis; Wichita Section—G. M. Allen, Paul Carter and H. W. Beeman.

The meeting was called to order at 9:30 A.M. by R. L. Townsend, Vice-President of the Mid-Southern District. A vote of thanks was extended to the South Texas Section for the excellent meeting arrangements. The delegates were unanimous in declaring the entire program an outstanding example of Texas hospitality and management. Regret was expressed for the absence of George N. Sieger, National President, Joe Magrath, National Executive Secretary and Howard Simms, Director. Invitations had been extended to each but other duties prevented their attending.

Announcement was made of the Annual National Meeting being held this year in Cleveland, Ohio, October 17th through 21st. All members were urged to attend as an outstanding program is being arranged with the theme "For Economy in Production—Weld." The *Welding Handbook*, 3rd edition, will be available late this year according to a report from headquarters. Orders will be taken during the Annual Meeting. All members were urged to keep this in mind and get their orders placed as well as for the new *Welding Metallurgy*.

The Vice-President presented a progress report for the entire district as well as the individual sections. While this report shows an increase in total membership the results were far from satisfactory. Actually, without the organization of the Dallas Section the district would have shown a substantial loss. This fact was emphasized by the presiding officer with instructions to the delegates to submit their future plans with their reports.

At this point in the proceedings Sam Walker, as Chairman of a special resolutions committee, read the official "Welcome to Dallas" as prepared by his committee. This resolution was then presented to John A. Wilson, representing the Dallas Section, after being signed by the District Vice-President as well as Chairmen or official delegates of the attending sections.

Our Vice-President called for reports by the various sections as to their activities for the past year and plans for the coming year. This was the time for dragging out the "family skeletons" or the dirty wash so to speak. Highlights of these reports are given below. Several good suggestions will be found that warrant your thought and actions if they can be adapted to your section.

Dallas Section

(Reported by John A. Wilson)

The first official meeting of the Dallas Section was held in May 1949. A second and concluding meeting for the year was held in June. Both meetings were well attended and Dallas seems to be off to a good beginning. The membership totals 60 with representatives from all phases of the welding industry. Mr. Wilson stated that they will need help in organizing programs and special events necessary to keep the section alive and active.

Colorado Section

(Reported by C. B. Swift)

Activities for the Colorado Section were somewhat unsatisfactory due primarily to the difficulties encountered in securing desired speakers. An educational program was cancelled for this reason; however, a special program on inert gas welding was held at a later date. This meeting was very successful.

A major project now in the formative stage is the organization of a division at Pueblo. It is hoped that 50 to 60 new members can be gained in this manner. *Denver is very emphatic in its desire to stay in the Mid-Southern District. Does not wish to tie to Salt Lake City.*

Kansas City Section

(Reported by Sam Walker)

Kansas City had a good year with a nice gain in membership. One of the outstanding meetings was the Welding Clinic held for two nights of two successive weeks. Subjects covered included design and welding of structurals, pressure vessels, etc., as given by Howard Simms and Vernon Rudd, inert gas welding by Ed Dato and heavy structurals (primarily bridge construction) by Lamotte Grover. A recommended program is that given by Mr. Rosengren, of Stearn-Rogers Co., on Flame Hardening.

For the first time Kansas City had a Christmas Party. This was a dinner-dance affair with the wives invited. On the negative side Kansas City does not recommend meetings on (1) Codes and Regulations; (2) Stump the Experts; (3) Welding Positioners.

Kansas City has in operation a plan for control of available funds. A budget is set each year alloting specific amounts for general expenses, educational fund, delegate expense to district meeting and supplying good literature and papers on welding processes to the public libraries. This latter project is just getting under way and much remains to be done.

To have a successful year and grow, plan good programs and *START NOW*.

C. E. Hardy, president of the Fraternal Order of Welders Brotherhood, asked for and received permission to appear before the meeting. His purpose was to explain the aims and purposes of their organization. No comments or discussion was offered by the delegates.

(*Secretaries Note:* Time out for a gift from Houston, a 10-gal. Stetson (simulated) and red bandanna. "Dead-Eye" Mosby immediately demonstrated the proper method of wearing this gear by proceeding to place the hat on backwards.)

Oklahoma City Section

(Reported by Bill Brewer)

The year's meetings were generally good with no one program considered outstanding. An educational program was held with the results O. K. financially, but questionable from the standpoint of interesting new members or offering worthwhile information.

The admission charge to nonmembers was justified on the following basis. In Oklahoma City there seems to exist a large group of nonmembers who appear for special interest meetings. While they have been approached with membership applications none have indicated interest. Since refreshments are served at each meeting the charge was made to help cover the expense. The section feels that the charge is just and fair.

Oklahoma City asked for a clarification of sustaining and supporting memberships.

It was stated that the increased fee is having a definite effect on securing new as well as maintaining present membership.

St. Louis Section

(Reported by J. H. Weigel)

Meetings for the past year were successful with attendance generally equaling the membership. A membership gain was shown for the year and more increase is the hope for the coming year. St. Louis has not conducted an educational program and needs information from other sections who have been successful in this type of activity.

One very outstanding program during the past year was "Castings vs. Welded Design" with foundry men and welders arguing pro and con. Anytime a meeting lasts until 1:30 A.M. it must be good. *St. Louis definitely desires to stay in the Mid-Southern District but will provide its own speakers without help from pre-arranged circuit meetings.*

South Texas Section

(Reported by H. V. Mosby)

The AMERICAN WELDING SOCIETY should be run as a business for successful and continued growth. Seventy-five per cent of their meetings were successful, with an increase of 300% in attendance; all are dinner meetings with free beer furnished by the Section. As a means of financing activities this section gets sponsorship by manufacturers, suppliers and others at specified rates. Recognition is given to each in their program announcements.

In the development of programs South Texas is opposed to educational meetings and code meetings. They do favor and feel the need of speakers on new methods and equipment such as the Specto Graph Analysis as developed by A. O. Smith Corp. As a final meeting for the year they plan to use an outstanding speaker of general interest, not necessarily on welding.

Tulsa Section

(Reported by J. B. Davis)

Programs generally were good and a fairly successful year was completed. The

Here's the Outstanding DC Arc-Welder Development of All Time

The *New* P&H NEMA-Rated Model WFA 300

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only special project was an educational program with the same speakers as used by Kansas City. It was found, however, that a free program will not draw the crowd. In other words, if it is free it must not be good. Moral—charge 'em.

Wichita Section

(Reported by H. W. Beeman)

Generally speaking Wichita experienced a very unsuccessful year. It was contributed primarily to a poor quality of programs as experienced by Kansas City and Denver. The meeting of most interest probably was "Stump the Experts." It is planned to make this or a similar program an annual affair. An educational program was planned but cancelled due to not being able to line up desirable speakers.

For the coming year a definite meeting schedule will be set up and maintained. More dinner meetings will be held. Local representatives of various manufacturers and suppliers will be invited to attend and let us know what is being done in their particular fields of business. An educational program is planned and will be held in November. . . . . .

Following the reports by various sections a general discussion was held during which the following questions were asked and suggestions made for better meetings and increased activities.

1. Increase membership by organization of divisions such as Pueblo as division of Denver, Augusta and Hutchinson as divisions of Wichita.
2. Provide badges for all members and name cards for visitors.
3. Stimulate meetings by inviting outstanding personalities of industry and business as guests of your Section.
4. Plainly mark your attendance committee and see that they are good greeters.
5. Two speakers on the suggested list, as provided, request payment for their appearance. This should be checked with headquarters to determine if there are others. New York Headquarter speaker lists should indicate if speaker expects pay and how much

The district was divided for discussion and preparation of 1949–50 meetings:

Northern Division—Sam Walker, Sec., Denver, Kansas City and Wichita.
Southern Division—Allen Wisler, Sec., Dallas, Oklahoma City, Tulsa and South Texas.

Adjourned for lunch.

The general meeting reconvened at 1:30 to consider the invitation of Oklahoma City and Tulsa to hold the annual meeting in their respective cities. By standing vote of 5 to 2 the sections' representatives awarded Tulsa the meeting which will be held July 15, 1950.

As a final word the Vice-President asked for a written report from each section on past year activities and forecast for coming year.

General meeting adjourned.

abstracts of
CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 10, D. C.

2,474,285—Bank Strip Welding Machine—William Francis Smith, Brooklyn, N. Y., assignor to Intl. Std. Electric Corp., New York.

Smith's apparatus covers a special machine for welding longitudinal wires to transverse selector pins in successive insulating bank strip bodies with successive crossover points between the wires and pins that are formed in paths extending diagonally with respect to the length of the wires.

2,474,593—Multipoint Spot Welding Mechanism—Henry B. Putnam, Muskegon Heights, Mich., assignor to Borg-Warner Corp., Chicago, Ill.

This machine includes a support frame having means adaptable for carrying an upper platen for movement in a vertical plane and a plurality of upper electrodes adjustably carried by the platen. A plurality of lower electrodes are each operatively carried by positioning means and are individually and pivotally associated with the support frame. Hydraulic piston means are associated with each of the lower electrodes and adapted to provide equalizing pressure to the individual lower electrodes to cause the necessary pressure contact between the respective upper and lower electrodes at the time of weld.

2,474,643—Method of Brazing Cemented Carbides to Steel—Clarence D. Webb, St. Clair Shores, Mich., assignor to Carboloy Co., Inc., a corporation of New York.

Webb's brazing method comprises placing a trimetal shim having two outer laminations of a silver-base solder and an intermediate lamination of copper between the cemented carbide body and a steel member. Next the assembled body, shim and support are heated to a temperature above the melting point of the silver-base alloy and below the melting point of copper to bond the assembly together.

2,474,787—Arc Welding Composition and Method of Making Same—George G. Landis, South Euclid, and Vladimir Peters, Lakewood, Ohio, assignors to The Lincoln Electric Co., Cleveland, Ohio, a corporation of Ohio.

This flux making method comprises mixing certain specified ingredients with a water glass solution and heating the resultant material from 700 to 1200° F. until substantially dry. Then the dried mass is ground to granular form and the ingredients are bonded together in uniformly distributed condition by dry water glass.

2,474,788—Welding Electrode—Frank G. Marbach, Cleveland, Ohio, assignor to Morrison Products, Inc., Cleveland, Ohio, a corporation of Ohio.

This welding electrode includes a head having an integral forwardly projecting portion of relatively reduced thickness. A tip is carried by the forwardly projecting portion and adapted for engagement with the work. This head has a forwardly converging cooling fluid passage portion formed thereinto from opposite edges thereof and forming a continuous passage which extends at least part way into the forwardly projecting portion of the head.

2,474,816—Welding Mechanism—Rufus L. Briggs, Melrose, Mass., assignor to Raytheon Mfg. Co., Newton, Mass.

This welding mechanism relates to the type having a fixed electrode and a

movable electrode. Means are provided for exerting a pressure upon the electrodes to place a predetermined pressure upon the work. Additional means are effective upon the application of the preselected pressure for sending a welding current through the work.

2,474,866—Three-Phase Welding Device—David Sciaky, Chicago, Ill., assignor to Welding Research, Inc., Chicago, Ill.

This patented welding device includes a welding transformer having a primary winding and a secondary load circuit. The primary circuit connecting to the primary winding of the transformer has two rectifiers of the transformer-type for connecting such primary circuit to a source of polyphase alternating current. Each rectifier includes a secondary winding for each phase of the alternating current source, and an electric discharge valve is connected in series relation with each such winding. One terminal of the primary circuit is connected to a neutral point of the secondary winding of each rectifier and the other terminal has connection with the discharge valve. The valves for each phase are connected in antiparallel relation and have operation so that one rectifier passes successive positive half cycles of the alternating current source to the primary circuit of the transformer as a uni-directional current in one direction and the other rectifier alternating passes successive negative half cycles of the alternating current source to the primary circuit as a uni-directional current in an opposite direction.

2,475,183—Apparatus for Stabilizing the Electric Welding Arc—Glenn J. Gibson, Chatham, N. J., assignor to Air Reduction Co., Inc., New York.

This electric arc-welding apparatus includes an electrode with a magnet surrounding the electrode. The electrode provides a magnetic flux field surrounding an annular extension of paramagnetic material in contact with the magnet and terminating approximately at the end of the electrode. A pole is provided having one active contacter with the magnet extending to and terminating in spaced relation to the end of the electrode. The magnet is adapted to round and direct the arc toward the pole.

2,475,209—Resistant Welding Electrode and Holder—Norman Albert Tucker, London, England, assignor to P. R. Mallory & Co., Inc.

Tucker's patent covers an electrode holder that has a longitudinal passage therein and a socket portion for receiving a welding tip. A cooling fluid conduit extends through the passage and has one end thereof positioned adjacent said socket. A helical spring is mounted on the end of the conduit and adapted for relative longitudinal movement with respect thereto. This spring comprises a laterally deformable extension of the conduit.

2,475,594—Gas-Electric Cutting or Welding Torch—Francois Georges Danhier, Schaerbeck, Belgium, assignor to La Soudure Electrique Autogene Societe Anonyme, Brussels, Belguim.

The patented device is adapted to simultaneously supply electric current and gas to a hollow electrode for electric arc welding or for electric arc cutting in an atmosphere of gas. The holder body has an interior passage which can be connected to a source of gas supply whereas a push connection is provided for the passage and adapted to receive the end of an electrode and seal thereto. Jaw means are provided for retaining the electrode in a desired position and for providing electrical energy therefor.

2,475,595—Cutting Torch—Roscoe C. Hunter, U.S.N., Holden, Utah.

Hunter's cutting device includes a plunger which conducts current to the hollow electrode positioned in this device. Additional means are provided for feeding oxygen to the electrode.

2,475,596—Method of Examining Welded Surfaces—John W. Dawson, West Newton, Mass., assignor to Raytheon Mfg., Co., Newton, Mass.

In this method, a thin film of material is positioned between two surfaces to be welded together and the material has a substantially different transparency to X-rays than the material forming the surfaces to be welded together. Then after the welding action, the weld area is exposed to X-rays to produce an X-ray image of the welded area and the areas at which fusion takes place have a substantially different transparency to X-rays than the areas which fail to fuse.

2,475,835—Method of Electric Arc Welding—Theodorus Hehenkamp, Eindhoven, Netherlands, assignor to Hartford National Bank & Trust Co., Hartford, Conn., as trustee.

This electric arc-welding method includes the steps of placing a layer of slag-forming material on a metal workpiece and keeping the running down point of the metal welding wire in such material. The distance between such wire point and the point of current supply to the wire are varied to maintain the Joule effect of the welding current in the wire to a value at which the speed of welding is at least 1.2 times greater than the specific welding speed if the intensity of the welding current were unchanged.

2,475,907—Welding of Metal Studs to Metal Plates—Bruce Martin, Chatham, England.

Martin's patent relates to apparatus for electric arc welding of metal objects in the form of studs, tubes, and the like to metal plates and the like. The apparatus includes a housing in which an electro-magnet is positioned with an armature being disposed transversely to the core of the magnet and adapted for limited movement toward and away from such core. A chuck is provided for the object to be welded and it is disposed exteriorally of the housing. A special switch device is provided which is closed and maintained closed by the armature when it is positioned within a determined distance from the magnet core.

2,476,187—Welding Mechanism—John D. Gordon, Pleasant Ridge, Mich., assignor to Progressive Welder Co., Detroit, Mich.

The mechanism of this patent particularly relates to a welding ram wherein two pressure cylinders are provided and has piston means associated therewith. The position of the supporting member is controlled by the piston and movement of such member in one direction is limited.

2,476,373—Combined Welder and Power Plant—Edward A. Hobart, Troy, Ohio, assignor to The Hobart Brothers Co., Troy, Ohio.

A power driven generator is provided with an exciter circuit for supplying current to the field of the generator in the patented type of a power plant. The generator has two pairs of windings and electric switch means are provided for connecting the windings in parallel or in series with each other so as to provide low or high voltage in the output circuit.

2,476,777—Combination Welding and Cutting Torch—Elmer H. Smith, Minneapolis, Minn., assignor to Smith Welding Equipment Corp., Minneapolis, Minn.

This patented device includes an enclosing member having axially aligned bores of different diameters and a low-pressure gas is supplied to the larger bore and high-pressure gas provided for the smaller bore. A body is received in the enclosing member and has spaced sealing faces for engaging with the axially aligned bores for sealing same. A resilient means constantly exerts a force on at least a portion of the body for retaining it in a sealing position in the enclosing member.

2,476,826—Method of Welding Bung-Reinforcing Structures for Barrels—Latham H. Conger, Jr., Akron, Ohio, assignor to The Firestone Tire & Rubber Co., Akron, Ohio.

A special welding apparatus is disclosed in this patent for securing a bung-reinforcing plate to the wall of a barrel section, which plate is positioned in an aperture in the barrel wall complementary in size to such bung-reinforcing plate. A groove is provided in the barrel section and a welding torch is continuously applied to progressive portions of the barrel wall adjacent the groove to provide molten metal for flowing into and at least partially filling the groove to weld the reinforcing plate to the barrel section.

2,476,882—Cyclic Electric Welder and the Like—George J. Lexa, Wauwatosa, Wis., assignor to Cutler-Hammer, Inc., Milwaukee, Wis.

Lexa's combination includes a plurality of electro-responsive windings that are to be progressively energized subject to predetermined timing and an alternating current supply source is provided. Separate and independently adjustable timing circuits are provided for each of the windings. Each of the circuits includes a grid type of electron tube and the tubes are connected to block conduction thereby and then the tubes are progressively unblocked to permit such tube and the circuits associated therewith to be rendered conductive.

TENTATIVE PROGRAM

AMERICAN WELDING SOCIETY

30th Annual Meeting
week of October 16, 1949

CLEVELAND HOTEL, CLEVELAND, OHIO

◗ ***Welding and cutting demonstration will be featured at the National Metal Exposition held during the week in the Cleveland Public Auditorium***

SUNDAY AFTERNOON, OCTOBER 16th—3 TO 5 P.M.

Registration and Get-Together

TECHNICAL SESSIONS

All Technical Sessions will positively start on time.

No Stenotype Reporter—Members desiring to discuss papers are urgently requested to prepare discussion in writing in advance of the meeting and to send copies to Headquarters, as those preparing written discussion will be given preference at the session. Members and guests giving extemporaneous discussion at meeting should forward a written discussion as soon as possible after the meeting.

MONDAY MORNING, OCTOBER 17th—9:30 A.M.

Three Simultaneous Sessions

STRUCTURAL DESIGN
Ball Room

Chairman—LaMOTTE GROVER
Air Reduction Sales Co.

Co-Chairman—F. L. PLUMMER
Hammond Iron Works

Design and Construction of a Modern Welded Deck Girder Highway Bridge
by NED L. ASHTON, State University of Iowa

Economical Design of Welded Buildings
by ROBERT E. ROBERTSON, JR., Saxe, Williar & Robertson, Engineers and Consultants

Proposed Design of Welded Rigid Frames for New York Subways
by MARTIN P. KORN, Consulting Engineer

A Strain Gage Test and Analysis of an Eighty-Foot H-Section Welded Truss
by A. WAIDELICH, The Austin Co.

PRESSURE VESSELS
Red Room

Chairman—A. C. WEIGEL
Combustion Engineering-Superheater, Inc.

Co-Chairman—G. M. TREFTS
Farrar & Trefts, Inc.

Importance of Design in Construction of Tanks and Pressure Vessels
by WALTER SAMANS, Chairman, Pressure Vessel Research Committee

Trends in Fabrication by Welding
by S. V. WILLIAMS, Struthers-Wells Corp.

Inert-Gas-Shielded Arc-Welding Aluminum Pressure Vessels
by A. J. HOPPER, Welding Engineers, Inc.

Notch Sensitivity of Mild Steel Plates
by A. B. BAGSAR, Sun Oil Co.

HARD FACING AND FLAME HARDENING
Rose Room

Chairman—R. P. TARBELL
Scott-Tarbell, Inc.

Co-Chairman—ELMER DELO
Haynes Stellite Company

Automatic Electric Hard Facing
by TURNER G. BRASHEAR, JR., Leader Welding and Manufacturing Co.

Hot Hardness of Hard-Facing Alloys
by HOWARD S. AVERY, American Brake Shoe Co.

Hard-Facing Applications in the Steel Industry
by J. J. BARRY, Air Reduction Sales Co.

Flame Hardening of Large Diameter Rounds
by S. SMITH, Air Reduction Sales Co.

a new edition

of

Welding Metallurgy

First published in 1940, this book has had several printings and has been distributed all over the world. To bring up to date, Mr. G. E. Linnert has prepared an extensive revision so that the new edition has 505 pages—150 pages more than the first edition. Many new illustrations have been added to bring the total to 203.

Material has been added to cover the new processes such as inert gas metal-arc welding; material has been added to provide greater coverage of the stainless steels.

A list of books is given at the end of each chapter for those especially interested in the subject covered by that chapter. Questions for school use are grouped together at the end of the book; they can be used for home study as well.

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Contrary to popular belief, the weld metal *does not become brittle*. Certified laboratory tests indicate very desirable results, including ultimate tensile strength of 73,200 psi, satisfactory 180 degree root bend, Brinnell hardness in the weld of 248 and in the pipe of 174.

"We used this procedure throughout the production of the chrome pipe," states the Chief Engineer, "and the lot was completed satisfactorily, quickly, and inexpensively."

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Already endowed with excellent usability characteristics in the vertical and overhead position as well as the horizontal, their new coating makes them particularly well suited for the ordinarily troublesome vertical-down welding.

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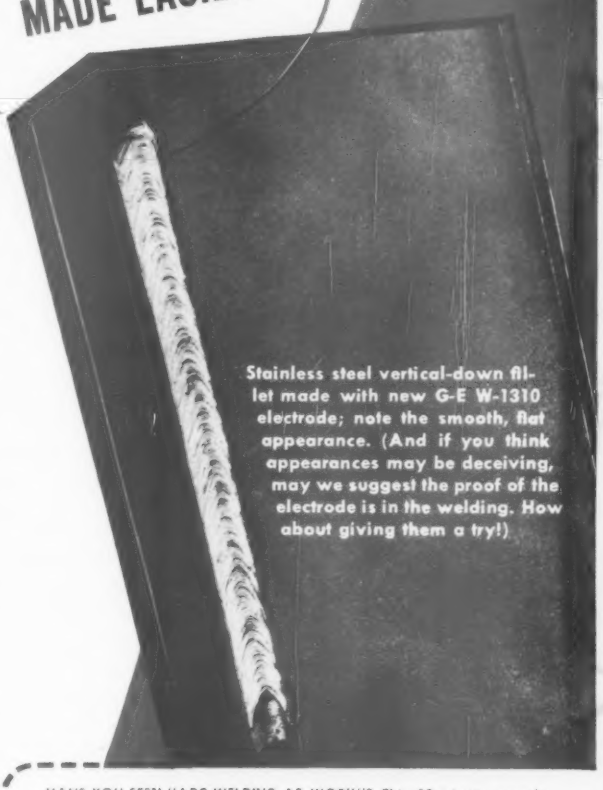
FOR OTHER WELDING JOBS there are some 40-odd additional types of G-E electrodes including a most complete line of low-hydrogen types, cast-iron, hard-surfacing, and phosphor-bronze electrodes, as well as mild-steel and general-purpose rod for manual or machine welding. Ask your G-E arc-welding distributor for information.



Stainless steel vertical-down fillet made with new G-E W-1310 electrode; note the smooth, flat appearance. (And if you think appearances may be deceiving, may we suggest the proof of the electrode is in the welding. How about giving them a try!)

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ARC WELDERS · ELECTRODES
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MONDAY AFTERNOON, OCTOBER 17th—2:00 P.M.

Three Simultaneous Sessions

NONFERROUS METALS
Red Room

Chairman—O. B. J. FRASER
The International Nickel Co., Inc.

Co-Chairman—F. G. FLOCKE
The Thornton Company

Arc Welding of Molybdenum
by I. S. GOODMAN, Westinghouse Electric Corp.

The Welding of High-Nickel Alloys to Other Metals
by G. R. PEASE and H. B. BOTT, The International Nickel Co., Inc.

Seam Welding Monel Metal to Steel
by ERNEST F. NIPPES, ALLAN R. PFLUGER and GERALD M. SLAUGHTER, Rensselaer Polytechnic Institute

EDUCATION
Rose Room

Chairman—R. A. WYANT
Rensselaer Polytechnic Institute

Co-Chairman—G. E. DOAN
Lehigh University

Welding in Engineering Education
by R. S. GREEN, The Ohio State University

Formal Training of Welding Personnel
by ALLEN C. TYLER, Acting Dean, LeTourneau Technical Institute

Continuation of Study of Welding and Welding Processes
by FRANK W. SCOTT, Marquette Mfg. Co., Inc.

RESEARCH
Ball Room

Chairman—ROSS J. YARROW
Republic Structural Iron Wks. Co.

Co-Chairman—L. K. STRINGHAM
The Lincoln Electric Co.

The Statistical Part in Welding Investigations
by B. B. DAY, Statistician, Director's Staff, U. S. Naval Engrg. Exp. Station

Brittle Failure and Size Effect in a Mild Steel
by K. J. STODDEN and E. P. KLIER, The Pennsylvania State College

Weld-Peening Investigations
by J. LYELL WILSON, American Bureau of Shipping

MONDAY AFTERNOON—4:30 TO 6:00 P.M.

Educational Lecture Series—Chairman, DR. G. E. DOAN

Parlor B, 3rd Floor Public Auditorium

Presiding—H. O. HILL
Bethlehem Steel Company

Designing for Welding
by H. W. PIERCE, New York Shipbuilding Corporation

MONDAY EVENING—8:00 P.M.

Ball Room

Chairman—GEORGE N. SIEGER, President
American Welding Society

Co-Chairman—M. S. SHANE, Chairman
Convention Committee

AWARDS OF PRIZES AND MEDALS

1949 ADAMS LECTURE

The Advantages and Disadvantages of Electric Welding as a Means of Fabricating Steel Structures, by W. M. WILSON, University of Illinois

TUESDAY MORNING, OCTOBER 18th—9:30 A.M.

Three Simultaneous Sessions

SYMPOSIUM ON SHIP STRUCTURE RESEARCH
Ball Room

Chairman—CAPT. C. M. TOOKE
Bureau of Ships, USN

Co-Chairman—
COMDR. R. D. SCHMIDTMAN
U. S. Coast Guard

Introduction
The Work of the Ship Structure Committee
by REAR ADMIRAL ELLIS REED-HILL, U.S.C.G. Chairman, Ship Structure Committee

Factors Influencing the Tensile Behavior of Notched Flat Plate Specimens
by PROF. S. T. CARPENTER and CAPT. W. P. ROOP, U.S.N. (Ret.), Swarthmore College

Correlation of Test Results
by DR. C. F. TIPPER, University of Cambridge, England

Tests of Slotted Steel Plates
by E. M. MacCUTCHEON, C. L. PITTIGLIO, David Taylor Mode Basin, U.S.N., and R. H. RARING National Research Council

Further Study of the Navy Tear Test
by NOAH KAHN and EMIL IMBEMBO, New York Naval Shipyard

RESISTANCE WELDING
Red Room

Chairman—T. EMBURY JONES
Precision Welder & Machine Co.

Co-Chairman—R. E. POWELL
Western Electric Co.

Material Consumption Rates and Flashing Characteristics
by WILLIAM N. PLATTE, Westinghouse Electric Corp.

Factors Affecting the Quality of Production Flash Welding
by E. SIRABIAN, Arnold, Schwinn & Co.

The Homopolar Generator Stored-Energy System for Resistance Welding
by THOMAS J. CRAWFORD, Progressive Welder Co.

Circuit Analysis of Frequency Changer Welders
by W. K. BOICE, General Electric Co.

MACHINERY WELDING
Rose Room

Chairman—CHAS. H. JENNINGS
Westinghouse Electric Corp.

Co-Chairman—L. S. McPHEE
Whiting Corporation

Weldment Design and Engineering Practice
by ANTHONY K. PANDJIRIS, Pandjiris Weldment Co.

Welding of Alloy Steel Shovel Buckets
by E. R. McCLUNG, Lukenweld, Inc.

Lowering Cost of Welded Construction
by OMER BLODGETT, The Lincoln Electric Co.

How to Cut Maintenance Cost with Aluminum Bronze Electrodes
by J. A. CUNNINGHAM, J. A. Cunningham Equipment, Inc.

TUESDAY AFTERNOON, OCTOBER 18th—2:00 P.M.

Three Simultaneous Sessions

SYMPOSIUM ON SHIP STRUCTURE RESEARCH
Ball Room

Chairman—FINN JONASSEN
The Committee on Ship Steel, National Research Council

Co-Chairman—J. LYELL WILSON
American Bureau of Shipping

Distribution of Relative Ductility in Steel Weldments
by L. J. KLINGLER and L. J. EBERT
Case Institute of Technology

Bend and Tensile Specimens Used as Indices of Performance and Weldability
by C. B. VOLDRICH and P. J. RIEPPEL, Battelle Memorial Institute

Effect of Cyclic Stress on Impact Transition Curve of Ship Steels
by PROF. J. M. LESSELLS and H. E. JACQUES, Massachusetts Institute of Technology

Axial Tension Impact Tests of Structural Steels
by W. H. BRUCKNER and N. M. NEWMARK, University of Illinois

RESISTANCE WELDING
Red Room

Chairman—R. H. ABORN
U. S. Steel Corp.

Co-Chairman—R. T. GILLETTE
General Electric Co.

Spotweld Consistency Studies
by JULIUS HEUSCHKEL and H. C. BITZER, Westinghouse Research Labs.

Spot Welding Heavy Gage Structural Steel
by ERNEST F. NIPPES and R. F. UNDERHILL, JR., Rensselaer Polytechnic Institute

Slope Control and Its Effect on Spot and Projection Welding
by I. W. JOHNSON, General Electric Co.

MISCELLANEOUS
Rose Room

Chairman—L. C. BIBBER
Carnegie-Illinois Steel Corp.

Co-Chairman—J. J. CHYLE
A. O. Smith Corp.

Welding of Zinc-Base Die Castings
by ROLAND H. OGDEN, Alladin Rod & Flux Mfg. Co.

Silver Alloy Brazing Stainless Steel
by C. H. CHATFIELD and A. W SWIFT, Handy & Harman

Magnaflux Inspection of Welded Storage Tanks
by F. A. UPSON, Standard Oil Company (Indiana)

High Energy Loading Method of Testing Steel Plate and Weldments
by G. S. MIKHALAPOV, Metallurgical Research and Development Co., Inc.

TUESDAY AFTERNOON—4:30 TO 6:00 P.M.

Educational Lecture Series—Chairman, DR. G. E. DOAN

Parlor B, 3rd Floor, Public Auditorium

Presiding—E. M. MacCUTCHEON
David Taylor Model Basin

Designing for Welding
by H. W. PIERCE, New York Shipbuilding Corporation

TUESDAY EVENING, OCTOBER 18th—8 P.M.

PRESIDENT'S RECEPTION
Red Room and Ball Room

Subscription buffet dinner, pay-as-you-go bar, dancing, music, etc.

WEDNESDAY MORNING, OCTOBER 19th—9:30 A.M.

Three Simultaneous Sessions

APPARATUS
Parlor C, Auditorium

Chairman—H. O. HILL
Bethlehem Steel Co.

Co-Chairman—A. M. SETAPEN
Handy & Harman

Design Features of a Welding Generator with Controlled Reactance
by J. M. TYRNER, Air Reduction Sales Co., and O. KOBEL, G. D. Peters & Co. of Canada, Ltd.

Measurement of Flux Densities in Steels for Magnetic Particle Inspection
by T. E. HAMILL, Naval Gun Factory

Economical Arc Welding
by S. OESTREICHER, Harnischfeger Corp.

RESISTANCE WELDING
Parlor B, Auditorium

Chairman—WILSON SCOTT
Westinghouse Electric Corp.

Co-Chairman—B. L. WISE
National Electric Welding Mach. Co.

Fatigue Tests of Spot-Welded Mild Steel and Stainless Steel Sheets
by PROF. GEORGES WELTER, École Polytechnique, Montreal, Canada

Spot Welding Galvanized Steel
by M. L. BEGEMAN, MILLARD L. HIPPLE and L. CULLUM, JR., The University of Texas

Electrical Resistance Offered by Non-Uniform Current Flow
by W. B. KOUWENHOVEN, and WILLIAM T. SACKETT, JR., School of Engineering, The Johns Hopkins University

Design and Application of Portable Resistance Welding Tools
by C. H. DAVIS, JR., The Budd Co.

ALUMINUM
Parlor A, Auditorium

Chairman—G. O. HOGLUND
Aluminum Co. of America

Co-Chairman—DANA W. SMITH
The Permanente Metals Corporation

The Economy of Shielded Arc Welding of Aluminum
by FRITZ ALBRECHT, The Glenn L. Martin Company

Shear Strength Consistency of Spot Welds in Alclad 24 S-T3
by J. C. BARRETT, The Glenn L. Martin Company

Heliarc Welding of Aluminum Alloys
by F. H. STEVENSON, Modern Metal Spinning & Mfg. Co.

WEDNESDAY AFTERNOON—4:30 TO 6:00 P.M.

Educational Lecture Series—Chairman, DR. G. E. DOAN

Parlor B, 3rd Floor, Public Auditorium

Presiding—H. W. LAWSON

Designing for Welding
by H. W. PIERCE, New York Shipbuilding Corporation

WEDNESDAY AFTERNOON, OCTOBER 19th—2:00 P.M.

BUSINESS MEETING

BOARD OF DIRECTORS MEETING

WEDNESDAY EVENING—7:30 P.M.

SECTION OFFICERS CONFERENCE

UNIVERSITY CONFERENCE

THURSDAY MORNING, OCTOBER 20th—9:30 A.M.

Three Simultaneous Sessions

ARCS AND ELECTRODES
Red Room

Chairman—J. H. HUMBERSTONE
Air Reduction Sales Co.

Co-Chairman—O. T. BARNETT
Metal & Thermit Corp.

Arc Welding Metal Transfer Analyzer
by R. C. McMASTER, D. C. MARTIN and A. LEATHERMAN, Battelle Memorial Institute

Heat Effects in Anode Spots of High-Current Arcs
by T. B. JONES, W. B. KOUWENHOVEN and MERRILL SKOLNIK, Johns Hopkins University

Application of Mild Steel Welding Electrodes
by F. R. STRATE, Air Reduction Sales Co., and R. I. STROUGH, Arcrods Corp.

Energy Distribution in Electric Welding
by CLARENCE E. JACKSON and A. E. SHRUBSALL, Union Carbide & Carbon Res. Labs.

RAILROAD
Rose Room

Chairman—ROY F. JOHNSON
Pullman-Standard Car Mfg. Co.

Co-Chairman—A. G. OEHLER
Editor, Railway Mechanical Engineer

Evolution of the Welded Freight Car
by L. E. GRANT, Chicago, Milwaukee, St. Paul & Pacific Railroad Co.

Oxy-Acetylene Pressure-Welded Rail Saves Maintenance Costs
by LEM ADAMS, Oxweld Railroad Service Company

Arc Welding in Railroad Shops
by E. DiLIBERTI, Air Reduction Sales Company

Heliarc and Railroad Applications
by H. E. GANNETT, Chicago, Burlington & Quincy Railroad

WELDABILITY
Ball Room

Chairman—A. B. KINZEL
Union Carbide & Carbon Res. Labs.

Co-Chairman—R. E. SOMERS
Bethlehem Steel Co.

Strain Aging in Welding Low-Carbon Structural Steel
by W. H. BRUCKNER and S. W. SANDBERG, University of Illinois

The High-Frequency Notch Bend Test
by BELA RONAY, U. S. Naval Engrg. Exp. Station

Studies Concerning the Strain-Aging of Arc Welds in Mild Steel
by A. E. FLANIGAN, University of California, Los Angeles

Synthetically Heat Treated Specimens for Weldability
by ERNEST F. NIPPES and WARREN SAVAGE, Rensselaer Polytechnic Institute

THURSDAY EVENING—8:00 P.M.

Chairman—J. F. LINCOLN, Lincoln Electric Company

Importance of Welding to Management, the Engineer and the Public
by W. T. Chevalier, McGraw-Hill Publishing Company

FRIDAY MORNING, OCTOBER 21st—9:30 A.M.

Three Simultaneous Sessions

INERT GAS WELDING
Ball Room

Chairman—C. B. VOLDRICH
Battelle Memorial Institute

Co-Chairman—C. A. LOOMIS
Bureau of Ships, USN.

Heliarc Welding in the Automotive Industry
by F. J. PILIA and R. H. BENNEWITZ, The Linde Air Products Co.

The Aircomatic Welding Process
by A. MULLER, G. J. GIBSON and E. H. ROPER, Air Reduction Sales Co.

Automatic Heliweld Applications
by H. O. JONES, Air Reduction Sales Co.

Applications for Helium in Inert Arc Welding
by M. J. CONWAY, General Electric Co.

STAINLESS STEEL
Red Room

Chairman—W. O. BINDER
Union Carbide and Carbon Research Labs.

Co-Chairman—E. VOM STEEG
General Electric Company

Corrosion Resistance of Molybdenum Bearing Stainless Steel Weld Metals
by R. D. THOMAS, JR., and ANTON L. SCHAEFFLER, Arcos Corporation

Problems Associated with the Welding of Stainless Clad Steel
by PERRY C. ARNOLD, Chicago Bridge & Iron Co.

Resistance Welding Stainless Steel Truck-Trailer Body Components
by BYRON GATES, The Budd Co.

Stainless Steel Fabrication by Inert-Gas-Shielded Arc Welding
by CHARLES D. BONIFIELD, The Globe Company

GAS CUTTING
Rose Room

Chairman—J. J. CROWE
Air Reduction Sales Co.

Co-Chairman—
H. E. ROCKEFELLER
The Linde Air Products Co.

New Developments in Oxyacetylene Cutting Machines
by W. BEGEROW and A. H. YOCH, Air Reduction Sales Co.

Steel Warehouse Shape Cutting with Electronic Tracers
by WILLIAM O. SPRINGER, Joseph T. Ryerson & Son, Inc.

Flame Cutting
by JAMES T. LEWIS, Lewis Welding & Engineering Corp.

Powder Cutting and Scarfing Process
by C. W. POWELL, Republic Steel Corp.

WELDING RESEARCH COUNCIL

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American Institute of Mining and Metallurgical Engineers, American Society of Civil Engineers
American Society of Mechanical Engineers, and Society of Naval Architects and Marine Engineers

Supplement to The Welding Journal, September, 1949

Spot Welding Galvanized Steel

The effect of welding current, timing and pressure are studied in the welding of galvanized steel. Physical and metallurgical investigations are reported as well as the results of preliminary study of the use of a refrigerated coolant in electrodes

by M. L. Begeman, M. L. Hipple and L. Cullum, Jr.

INTRODUCTION

SPOT welding as a manufacturing process has long been accepted as an economical and rapid means of fabricating light- and medium-gage metal. However, the spot welding of galvanized steel and other coated metals has not gained wide use because of the lack of information as to the most effective welding conditions. In spot welding galvanized steel certain varying factors are introduced which are not found in that of ordinary steel and hence conditions for operation must be changed accordingly. One of these factors is the low melting temperature of zinc which may cause the zinc to be lost by flashing or extrusion from beneath the electrode during the welding operation. Another is the affinity which zinc has for copper, resulting in excessive pickup of the zinc coating by the electrode if welding conditions are not correct. A further factor is the variation in coating thickness of the galvanized sheets by both the hot-dip and electrolytic process. (These tests, performed entirely on hot-dipped steel, often showed considerable variation in coating thickness on a given sheet.) Finally, iron-zinc alloys formed at high temperatures are found to be somewhat hard and brittle even though both materials are originally fairly ductile. These facts all indicate that the spot welding of galvanized steel is not without its problems and certainly an understanding of the major welding variables and techniques is of prime importance. It will be the object of this paper to determine which of the above factors are of major importance in the commercial welding of galvanized steel, and to suggest correct welding procedure.

During the past two years there have been made several coordinated investigations on spot welding at the University of Texas. Specifically, these investigations have delved into the problems relating to the selection of the major welding variables as they pertain to spot welding of 20- and 22-gage galvanized steel of various thickness coatings. In order to arrive at some useful conclusion, the investigation was limited primarily to a study of the effect of the "major" variables that are deemed to have the most pronounced influence upon the weld strength. All "minor" variables were fixed at what is believed to be optimum conditions. Extensive

M. L. Begeman is Professor of Mechanical Engineering; **M. L. Hipple**, Instructor of Mechanical Engineering; and **L. Cullum, Jr.**, a Graduate student in Mechanical Engineering, at the University of Texas, Austin, Tex.

This paper is scheduled for presentation at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

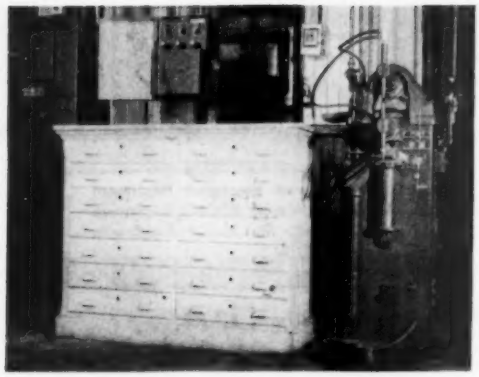


Fig. 1 Acme 75-kva. spot welder with auxiliary sequence and thyratron control panels

use of recommendations of other investigators was made in selecting the optimum conditions of the "major" and "minor" variables. Upon the completion of this phase of the investigation some work was done in ascertaining the number of successive welds that could be made with one set of electrode tips before excessive pickup of zinc changed the weld strength and appearance. Tests on this phase of the work are still in progress. However, these tests led to the belief that if the water circulated was replaced by a refrigerated fluid at low temperature the tip life would be increased and less zinc would be picked up by the electrodes. These assumptions appeared to be reasonable since both the mechanical strength and electrical conductivity of the copper-alloy electrodes increase as the temperature decreases and also less zinc would be picked up in the spot-welding operation if the electrodes were held at a low temperature. Much help was obtained in this phase of the investigation by studying the work of others who had applied refrigeration to the cooling of electrodes in the spot welding of aluminum alloys and other metals. This phase of the investigation included a comparison of the physical properties of spot welds at normal and low coolant temperatures with the idea of determining whether or not increased tip life could be obtained by refrigeration of the tips. A further object of these tests was to observe the cold tips' effect on surface appearance and weld strength.

EQUIPMENT USED IN TESTS

All the welding in this investigation was performed on an Acme 75-kva. spot welder, Type 3-18-75, Style SOAR, operated with 220-v., 60-cycle, single-phase alternating current. The welder, shown in Fig. 1, was of the air-operated rocker-arm type and the welding cycle was started by means of a two-stage floor switch. A General Electric Type CR 7503-F, sequence control panel was used in connection with the welder to control the timing of events in the welding cycle. Four thyratron circuits were provided; one for each of the events in the welding cycle—squeeze period, weld period, hold period and off period. The heat control (or amount of welding current used) was by the phase-shift method and the heat-control dial, located on the control panels, was calibrated in 1% steps from 20 to 100%. The percent heat represents the relative magnitude of the welding current to the maximum possible welding current.

A special jig, shown in Fig. 2, was constructed to position the specimens, thus facilitating and insuring accurate component alignment and overlap. It was designed in such a fashion as to accommodate various widths and lengths of specimens by merely adjusting the side and end strips.

The weld strength of all specimens was determined by a Southwark-Tate-Emery 120,000-lb. Universal testing machine. Two Templin grip holders, especially adapted for sheet-metal material, were used in the test.

CONSIDERATIONS AFFECTING THE SELECTION OF THE WELDING VARIABLES

Because of the large number of possible variables in spot welding it was necessary to make several decisions on procedures and machine settings before the work of preparing the test specimens could be undertaken. In general, these values could be placed in two groups: those which had considerable effect upon the character of the weld, and those which had only a minor influence. Major variables are: (1) the welding current or percent heat, (2) the weld period, (3) the tip pressure and (4) the material being welded. Minor variables are: (1) tip shape, size and condition, (2) electrode tip cooling rates, (3) squeeze time, (4) hold time, (5) electrode closing speed, (6) throat depth and horn gap, (7) size of material or welding fixture and (8) the surface prepara-

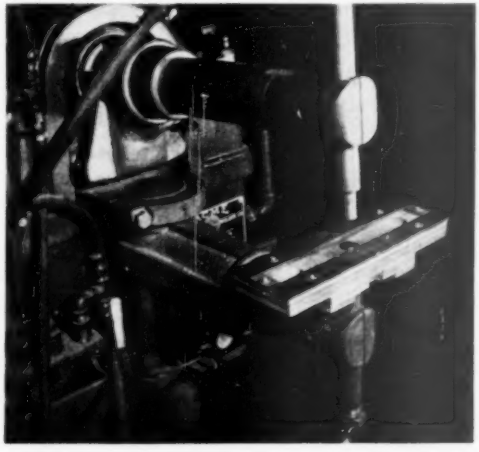


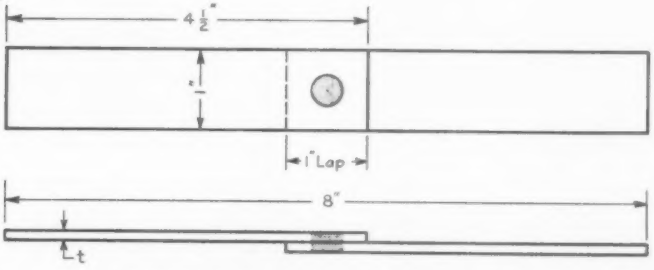
Fig. 2 Welding jig in position

tion. The decisions on the above points were reached by either studying the work of previous investigators or by actual preliminary tests. Considerations affecting these points and the decisions arrived at are as follows:

Welding Current or Percent Heat. The operating range of the welder used in this investigation was from 40 to 100% heat corresponding to a minimum of 9,160 amp. and a maximum of 25,160 amp. when welding 22-gage galvanized steel. First tests by Cooke[4] used welding-current settings varying from 50 to 100% in increments of 10%. Later tests by Hipple[9] used percent heats varying from 40 to 100% at intervals of 15%. The selection of these intervals was influenced by the work of other investigators on similar type materials.

Weld Period. Previous investigators recommend weld periods of short duration particularly on steels having a low melting point coating. Short time was found to minimize oxidation rates, lengthen electrode life, reduce surface deformation to a minimum and give a better weld strength consistency. Since it is strongly recommended that a relatively high welding current flow for a short duration of time, it was considered advisable to adopt as low a period of weld time as possible. Early experiments showed that at weld periods of less than 3 cycles the results were inconsistent in quality while at weld periods greater than 15 cycles there was no additional increase in strength. Hence, weld times in increments of four cycles were selected as follows: 3, 7, 11 and 15 cycles.

Tip Pressure. Since zinc melts at 786°F. and boils at 1706°F., there is a tendency in spot welding for the zinc to vaporize and form an oxide at the surface. Due to this narrow range between melting and boiling points of the zinc coating, high tip pressure should be used to minimize the vaporization tendency of the zinc. The Resistance Welding Committee of the AMERICAN WELDING SOCIETY recommends that pressures be increased 25% over those used on noncoated steels to compensate for the increased contact resistance of the coating. Besserer's[1] work on mild steel sheet with this same welder concluded that a minimum value of 35 psi. (305 lb.) gave consistent results. As a result of this work and other preliminary tests, an operating range from 30 to 90 psi. (268 to 913 lb.) was chosen in most of the tests using 15 psi. increments.



SPOT WELDING SPECIMEN

Figure 3

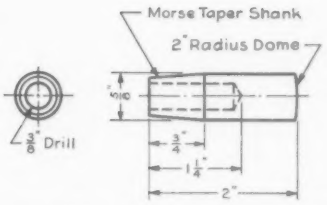


Fig. 4 Electrode tip used in tests, Elkaloy A, No. 1325.

Material Being Welded. Early tests on galvanized steel by Cooke used 20-gage Bethlehem prime galvanized steel having a coating weight of 1.26 oz. per square foot. However, since it was of interest to ascertain the effect of various weight coatings a light gage of galvanized steel with three representative weights of coatings was selected for all the later tests. Three weights of coating, namely 1.05 oz. per square foot, 1.53 oz. per square foot and 2.25 oz. per square foot were furnished through the courtesy of the Bethlehem Steel Co. A drawing of the test specimen used is shown in Fig. 3.

Electrode Tips. The electrode tips used in these tests were from recommendations of the P. R. Mallory Co., The American Welding Society Resistance Welding Committee and others. From this information Elkaloy A, No. 1325 electrode tips, as shown in Fig. 4, were selected for the first tests. The contact face of the tip was machined to a 2-in. radius dome.

Electrode Tip Cooling Water. Insufficient electrode tip cooling causes excessive electrode pickup and correspondingly decreases electrode life. Consequently, the control manufacturer's recommendation of 1 1/2 gal. of fresh tap water (per minute) for each electrode was followed for all tests except those using a refrigerated fluid.

Squeeze Time. Investigations by Brown[2] on aluminized steel included a study of the squeeze periods from 2 to 60 cycles. These tests showed that squeeze time had little influence on the weld strength except at very low values where considerable flashing occurred. A squeeze time of 30 cycles was used throughout the first part of the research work to insure uniform results. In later tests on refrigerated electrodes a squeeze time of 15 cycles was used.

Hold Time. Previous investigators found a hold time of 3 cycles to be ample since solidification takes place very rapidly. First tests used 30 cycles to allow ample time for thermal equilibrium to be reached, while for the tests using refrigerated electrodes this value was reduced to 5 cycles.

Electrode Closing Speed. The horn closing speed selected was approximately 3 ft. per second. This

speed did not result in any appreciable mushrooming of the electrodes or deformation of the work.

Throat Depth and Horn Gap. The size of the work being welded, the magnitude of the welding current desired, the electrode tip pressure and the material being welded dictate the optimum settings. The minimum throat depth and horn gap provides the greatest welding current, since any increase in area of the secondary current will increase the impedance and consequently lower the effective secondary current. Therefore, in order to obtain as high a welding current as possible, the area was held to a minimum using 12-in. horns and an 8-in. spacing. In the later tests using a refrigerated cooling liquid it was found necessary to increase the distance between the arms to 10 in. in order to properly accommodate the electrode adapters which carry the tip refrigerant.

Surface Preparation. The purpose of surface preparation is to eliminate fluctuations in the heat of welding due to variations of the contact resistance and also to minimize the chemical deposits due to handling or to the atmosphere. Since uniform results were desired in the test specimen welds, it was decided that a uniform procedure should be established for the surface preparation of all specimens. This consisted of removing all burrs from the shearing operation, degreasing in carbontetrachloride and buffing on the component side that was to be placed next to the electrode. All this was done just prior to welding. Some preliminary tests on welding specimens, prepared in various ways and with no surface preparation at all, showed that surface preparation had little effect on the strength of the weld, but in the interest of uniformity the above procedure was followed.

PROCEDURE FOLLOWED IN MAKING WELDS AND TESTING

The welding was accomplished by placing two components into the welding jig and making a single spot weld in the center of the overlapped components. Upon completion of each weld the specimen was numbered and set aside for further tests. Four specimens were made at each machine setting, the first three being set aside for physical testing purposes and the remaining one reserved for metallurgical study. Successive welds were made at intervals of 30 sec. thereby insuring the return of the electrode tips to thermal equilibrium.

The combination of welding variables selected for the first phase of this investigation included:

Air pressure, psi.	30	45	60	75	90
Electrode pressure, lb.	268	431	593	755	913
Weld period, cycles	3	7	11	15	...
Percent heat	40	55	70	85	100
Welding current, amp.	9160	12,220	15,460	20,070	25,160
Material coating, oz.	1.05	...	1.53	...	2.25

The procedure employed in making this series of welds was as follows: With the air-pressure gage set at 30 psi., the weld time was set at 3 cycles, the percent heat was varied from 40 to 100% at 15% intervals. For each set of conditions, four welds were made on the

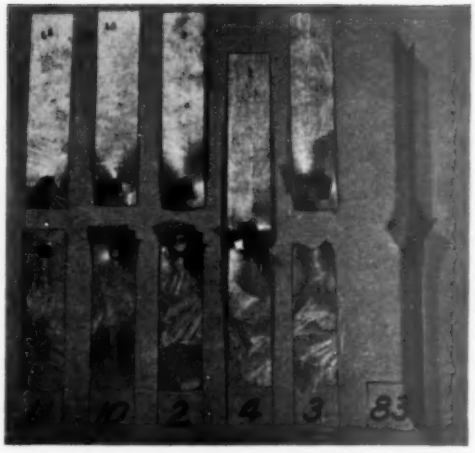


Fig. 5 Examples of specimen failures

light, medium and heavy coating materials. Upon completion of this combination of variables, the weld time was increased to 7 cycles and the procedure was repeated. Upon completion of weld periods of 3, 7, 11 and 15 cycles, the air pressure was increased from 30 to 45 psi. where the foregoing procedure was repeated. Similarly the air pressure was increased from 45 to 60, to 75 and, finally, to 90 psi., thus completing 1200 individual welds which included 100 sets of combinations of major welding variables.

While tips were installed at the beginning of each series of welds for each air pressure in the first phase of this investigation, in no case were over 60 welds made with one set of tips.

In the second phase of this investigation, the air pressure, weld period and welding current were held constant for 100 consecutive welds for each weight of galvanized coated steel. Attention is called to the fact that only the magnitude of the welding current was

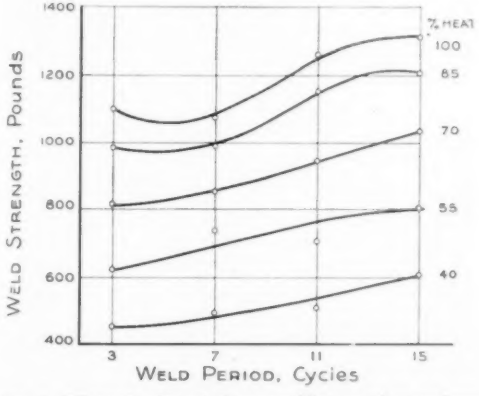


Fig. 6 Effect of weld period upon weld strength at various welding currents for all electrode tip pressures

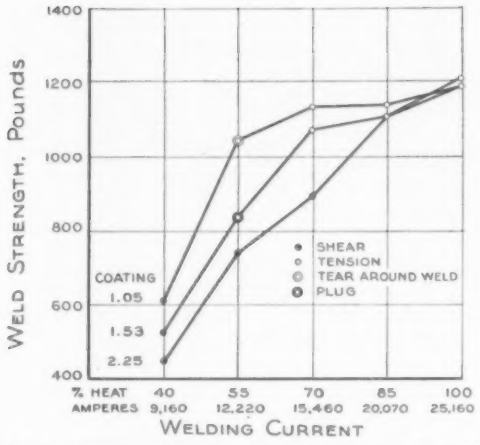


Fig. 7 Comparing the effect of welding current on weld strength of 3 thicknesses of zinc coating at 750-lb. tip pressure and 7-cycle weld period

changed for the three weights of coating in these tests, the balance of the machine settings remaining the same as those in the previous tests. A new set of electrode tips were placed in the holders at the beginning of each of these runs and were used throughout the 100 consecutive welds. No dressing or refacing was given to any of the electrode tips during these runs. The minimum time interval between welds was 5 sec.

Before testing to destruction in the Southwark-Tate-Emery Universal testing machine the surface indentation of each specimen was carefully measured. Upon completion of the test, the strength, type of failure and any peculiarities in the test were recorded for each specimen. Breaking loads for each set of three specimens were averaged and it was this figure that was used in plotting the various curves. A number of the specimens were sectioned through the weld and mounted in bakelite for metallurgical examination.

Although the breaking tests performed were to test the weld specimens in shear, failure in all but a few (fusion only of zinc coating) was in a combination of bending and shear. As the load was increased beyond a certain point, a bending action took place which accelerated the failure. This is clearly shown in Fig. 5 which illustrates a variety of ways that a specimen fails. The types of failure shown are, respectively, shear, plug, combination of tear around the weld and plate tension, plug torn out of each component, plate tension and plate tear. Tension failures across the plate adjacent to the weld were quite common and showed high strength.

PHYSICAL CHARACTERISTICS OF THE WELD

Composite curves (those where the average results for all settings of one of the major independent variables are plotted against the dependent variables) were plotted to present a graphic form of analogy. The composite curves of Fig. 6 show the effect of weld period upon weld strength at various welding currents for all electrode tip pressures. As the weld period is increased from 3 to 15 cycles, there is a uniform gradual increase approaching a straight line function in weld strength of 150 to 200 lb. As the magnitude of the welding current is increased in 15% heat steps, the weld strength increases substantially. The curves begin to flatten out upon reaching the 11-cycle weld period; this indicates that long weld periods do little to increase weld strength. These curves illustrate the predominant role that the welding current has upon welding strength, as compared to the less significant role the weld period has upon weld strength.

Figure 7 compares the effect of welding current on weld strength of three thicknesses of zinc coating at a 750-lb. tip pressure and 7-cycle weld period. The weld strength differential between 9,160 and 17,000 amp. is approximately constant between the three coatings, but the curves become asymptotic at 20,070 to 25,160 amp. welding current. This indicates that the resistance is directly proportional to the thickness of the coating in the optimum operating range, as one would expect, and consequently, approximately proportional to the weld strength and welding current. Naturally for similar welding conditions, the light weight coating of galvanized steel produces welds of higher strength than welds of heavier coating specimens. It is interesting to note that at 100% heat the strengths of all three coatings at these fixed welding conditions were about the same.

The composite curves of Fig. 8 show the effect of tip pressure on weld strength at various welding currents for all weld periods. At low welding current (9000 to 12,000 amp.) the strength drops off perceptibly as the tip pressure is increased from approximately 600 lb. to a maximum pressure of 900 lb. At the optimum range of welding current (approximately 15,000 amp.) the most suitable tip pressure for good weld strength is from 450

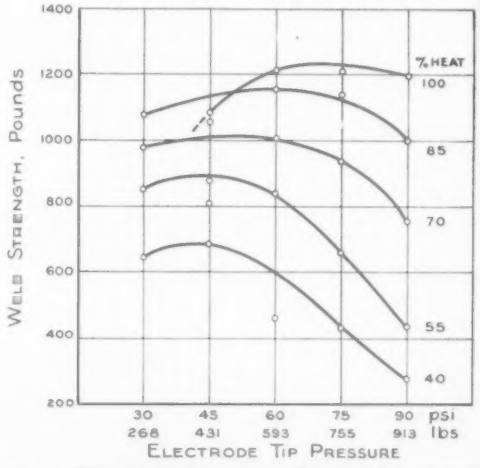


Fig. 8 Effect of tip pressure on weld strength at various welding currents for all welding periods

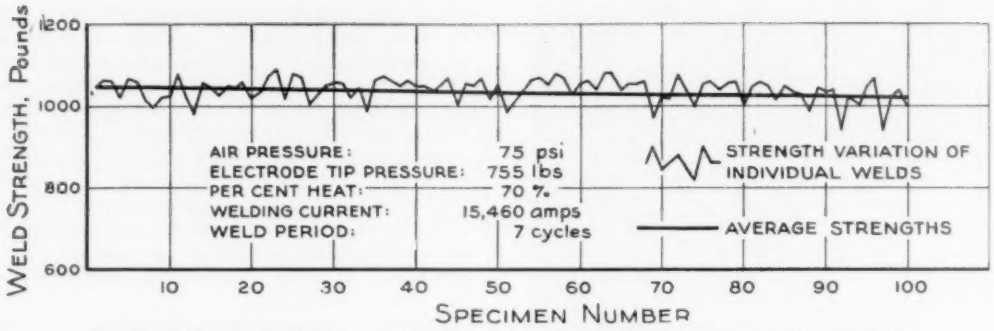


Fig. 9 Weld strength of 100 consecutive welds made with 1.53 oz. per square foot coating material

to 750 lb. As the welding current is further increased, the optimum tip pressure increases to a maximum of approximately 750 lb. The rather high weld strength at low tip pressures may be rationalized by noting that the nugget diameter is smaller at low tip pressures; likewise the area of electrodes in contact with the material being welded is smaller and, consequently, the current density is higher thus producing a more penetrating and satisfactory weld.

The phase of the investigation whereby 100 consecutive welds were made on each coating weight of material without redressing the tips between welds is graphically described by plotting the breaking loads against the consecutive weld. Figure 9 shows a log-plot of 100 consecutive welds for the 1.53 oz. per square foot coating material. The variation in weld strength did not exceed plus or minus 5% from the average. The average trend shows a gradual decline of 13 lb.—of insufficient magnitude to formulate any conclusions other than that the weld strength remained approximately constant. Therefore, the effect of electrode pickup on weld strength for 100 consecutive welds was negligible.

Figure 10 shows a comparison of average weld strength for 100 consecutive welds on specimens of the three different coatings. All conditions were the same for these three runs with the exception of the magnitude of the welding current. A welding current of 13,250 amp. was used on the 1.05-oz. coating, a welding current of 15,460 amp. was used on the 1.53-oz. coating and a welding current of 20,070 amp. was used on the 2.25-oz. coating. The curves depicting the three average trends of weld strengths for the 100 consecutive welds almost overlap. Apparently electrode tip pickup of the galvanized coating is not as detrimental to weld strength as currently believed. In fact the electrode tips were in good condition upon completion of each run. Had the welding current been less severe at a slight sacrifice of weld strength, the 2-in. radius dome "Elkaloy A" tips, it is believed, could have been used for several hundred more consecutive welds.

METALLURGICAL CHARACTERISTICS OF THE WELD

Inasmuch as welding is primarily a problem in metallurgy, much information on the characteristics of the weld is expected of the metallurgist. The metallurgy of spot welding is simply one of understanding the materials to be joined and the current distribution desired at the spot. Metallographic sampling will show the size, shape, penetration, location and structure of the weld nugget as well as the structure adjacent to the weld, the results of heat distribution in the welding operation and the presence of porosity and cracks.

Low-carbon steel such as that used in this investigation presents a minimum of metallurgical problems;

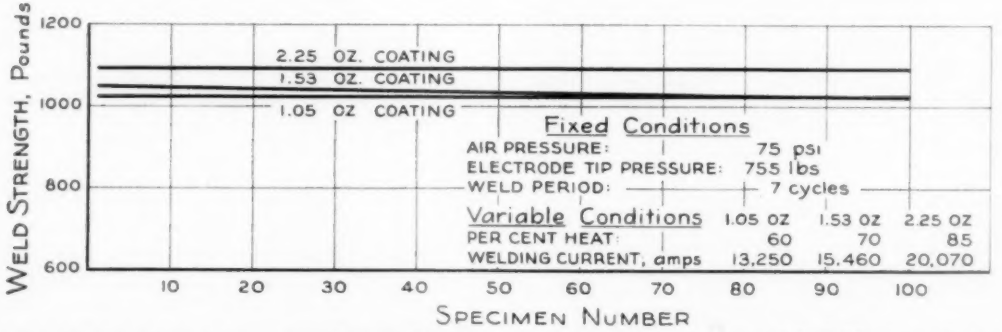


Fig. 10 Comparison of average weld strength for 100 consecutive welds on specimens of the 3 different coatings

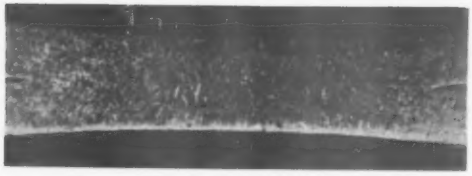


Fig. 11 Cross section of weld in 1.05-oz. coated specimen made at optimum welding conditions. Magnification 10 ×

however, the coating, particularly in the case of galvanized steel, presents operating problems that vitally affect the metallurgical aspects of the weld. The heat applied by passing current between the electrodes melts the metal at the interface, and upon cessation of current flow, rapid cooling takes place solidifying the nugget. What actually takes place in this very low carbon steel is that upon passing welding current, a rapid temperature rise results at the weld interface and spreads to the area between the electrodes. The zinc coating melts and is largely expelled adjacent to the weld nugget. The alpha iron of the parent metal is heated rapidly thereby transforming into gamma iron and then into delta iron before the termination of current flow allows the temperature to rapidly return through the gamma or austenitic iron back to a combination of ferrite and pearlite having a structure that is predominantly dendritic. Changes of rate of cooling during solidification of the nugget produce a number of well-defined zones of microstructure.

Specimen 301 in Fig. 11 shows the cross section at 10 × magnification of an optimum weld in the 1.53-oz. per square foot weight coating. Figure 12 shows the appearance of the same specimen near the center of the weld nugget at a magnification of 200 ×. Notice the discontinuous network of microconstituents along the grain boundaries and at the dendritic interstices. It is believed that the rapid cooling rate from the molten to the solid stages did not permit complete diffusion of the microconstituents and, therefore, the dendritic structure does not contain evidences of pearlite and ferrite grains. The central structure consists of discontinuous cast metal layers produced by alternate heating and cooling of the parent metal occurring in each successive

Fig. 12 Microstructure of weld at center of weld nugget. Magnification 200 ×

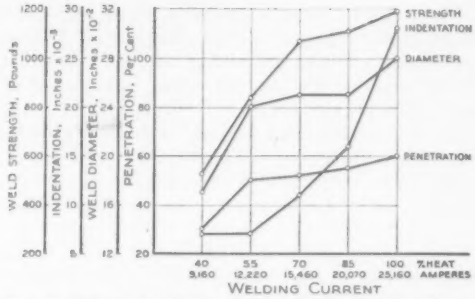


Fig. 13 Effect of weld current on the weld strength, indentation, nugget diameter and penetration of welds using a 7-cycle weld period and 755-lb. tip pressure on 1.53 oz. per square foot coating of galvanized 22-gage steel

cycle of the alternating welding current. The result is an intracrystalline precipitation of the ferrite.

Figure 13 shows the effect of weld current on the weld strength, indentation, nugget diameter and penetration of welds using a 7-cycle weld period and 755-lb. tip pressure on 1.53-oz. per square foot coating of galvanized 22-gage steel. Notice that as the welding current is increased the strength, diameter, indentation and penetration also increased. The nugget diameter and penetration curves are similar; these characteristics are a function of the current densities. The most desirable welding range is where these curves flatten out, i.e., between 15,000 and 20,000 amp. current; within this range the weld strength approaches a maximum, while the indentation is not excessive. In other words a weld strength of approximately 1100 lb. results from a 15,000 to 20,000 amp. welding current creating a nugget diameter of 0.25 in., a penetration of 60% and a total surface indentation of approximately 0.015 in.

CONCLUSIONS

The following conclusions have been established from experimental results. Naturally these conclusions apply to the spot welding of galvanized steel, essentially within the scope and range of the operating conditions selected in this investigation.

1. Weld strength increases proportionately with an increase in welding current.

2. Weld strength increases with a minimum weld period of 3 cycles ($^1/_{20}$ sec.) to 15 cycles ($^1/_4$ sec.); the weld strength appears to become constant when using weld periods above 15 cycles.

3. At low magnitudes of welding currents, an increase in electrode tip pressure greatly decreases weld strength; at high welding currents, the weld strength is approximately constant for all electrode tip pressures.

4. Surface indentation becomes excessive at 600-lb. electrode tip pressure when using high welding currents.

5. Weld period has little effect upon surface indentation.

6. The nugget structure of all welds is essentially dendritic.

7. Welding currents in excess of 20,000 amp. cause excessive flashing on galvanized coatings up to 1.53 oz. per square foot; excessive flashing does not occur under 23,000 amp. on 2.25 oz. per square foot coating of galvanized 22-gage steel.

8. Excessive flashing occurs at magnitudes of welding currents in excess of 15,000 amp. at low tip pressures.

9. There is essentially no decrease in average weld strength for a series of 100 consecutive welds without electrode tip dressing.

10. Elkaloy A electrode tips having a 2-in. radius dome remain in good condition after 100 consecutive welds without tip redressing when spot welding galvanized steel.

11. The optimum welding condition for 1.05 oz. per square foot coating of 22-gage galvanized steel is 13,000 to 15,000 amp. welding current at 10- to 7-cycle weld period using a 600- to 700-lb. electrode tip pressure.

12. The optimum welding condition for 1.53 oz. per square foot coating of 22-gage galvanized steel is 14,000 to 16,000 amp. welding current at 10- to 7-cycle weld period using a 600- to 700-lb. electrode tip pressure.

13. The optimum welding conditions for 2.25 oz. per square foot coating of 22-gage galvanized steel is 19,000 to 21,000 amp. of welding current at 10- to 7-cycle weld period using a 600- to 700-lb. electrode tip pressure.

14. An increase of 2200 amp. welding current for each additional 0.5 oz. per square foot of zinc coating over and above 1.0 oz. per square foot will give equivalent weld strengths using a 700- to 750-lb. electrode tip pressure and a 7-cycle weld period.

15. The peculiar affinity that zinc has for iron, particularly near the critical temperature of zinc, combats effectively corrosion tendencies of exposed parent metal.

USE OF A REFRIGERATED COOLANT IN ELECTRODES

Equipment for Cooling

Since the primary object of this phase of the investigation was the study of spot-welding characteristics at low temperatures, a rather elaborate cooling arrangement for the electrode tips was required. The plan of simply expanding a refrigerant into the tips was rejected in favor of the more complicated two-step system because of the possibility of blowing out a welder tip and losing the refrigerant charge, as well as the difficulty of controlling and measuring tip temperature.

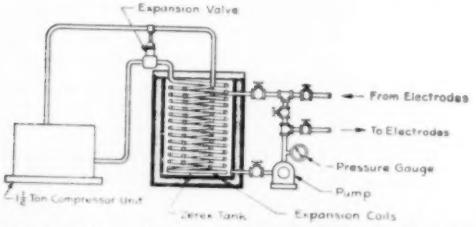


Fig. 14 Schematic diagram of refrigerating system for electrode coolant

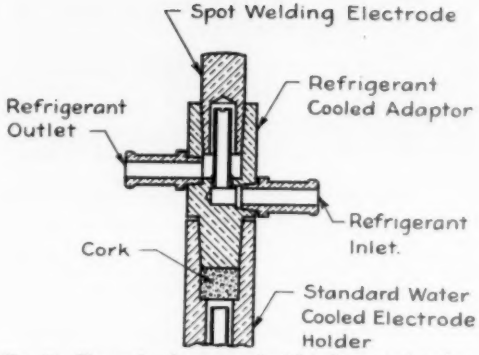


Fig. 15 Electrode adapter used with refrigerated coolant

The system setup consists of two general parts: (1) a refrigeration circuit expanding Freon into a cooling coil and (2) a circulation system which carries the cooled Zerex solution (ethylene glycol and rust inhibitor) through the welding tips. Figure 14 shows a schematic diagram of the system.*

The refrigeration circuit shown utilizes a Frigidaire "Flowing Cold" unit of $1^1/_2$-ton capacity driven by a small motor which also drives the air circulation fan for the air-cooled condenser coil. Appropriate pressure valves and gages were provided in both suction and exhaust sides of the compressor to allow full control of the flow to the expansion coil. The coil itself is 10 in. in diameter and consists of 19 turns of $^3/_8$-in. hard-drawn copper tubing.

The circulation circuit consists of an insulated tank of 5-gal. capacity in which the expansion coil is located, with pump, necessary valves and pipe connection to the electrode tips. The tank serves as a cooling vat for the Zerex coolant which is circulated through the system by the small pump. A 50% solution of Zerex was used since it gave a freezing point of $-35°$ F. which was outside the range desired in this work.

In order to avoid cooling the entire electrode and a portion of the welder horn, special adapters as shown in Fig. 15 were used to restrict the coolant flow to the tips themselves. Behind the adapter in the electrode, the normal water flow was maintained to keep the electrodes and horns from becoming frost-covered. The cork insulator, between the adaptor and the water, aided in preventing ice formation and water circulation stoppage. The temperature of the coolant was measured by means of a thermometer suspended in the top of the tank directly in the flow of the coolant returning from the electrodes.

Specimens Used

The material used in this phase of the test was 22-gage mild steel, cold-reduced, with coatings of zinc applied

* This arrangement is similar to that used by Dr. F. R. Hensel, E. I. Larsen and E. F. Holt in their work on "Refrigerant Cooled Spot-Welding Electrodes," The Welding Journal, December 1942 pp. 583-s to 597-s.

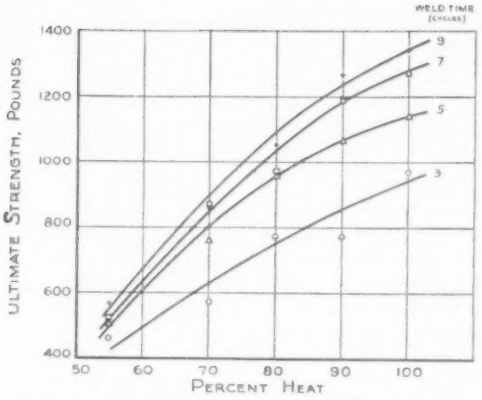


Fig. 16 Weld strength of medium coated steel for various welding conditions at a coolant temperature of −5°F.

by the hot-dip process. Three coating weights of 1.05, 1.53 and 2.25 oz. per square foot were supplied on this thickness of steel. Specimens were cut to the same standard test size as used in the first tests, 1- by $4^1/_2$-in. rectangle, and the rough edges left by the shearing operation were removed by grinding slightly. Prior to welding, the specimens were mechanically cleaned by buffing on a wire brush buffer wheel (0.003-in. wires) and the surface was then cleaned by carbon tetrachloride.

WELDING CONDITIONS FOR REFRIGERATED ELECTRODES

Dr. Hess and his associates at Rensselaer Polytechnic Institute[7, 8] found that benefits from cold tips could be obtained only at optimum welder settings. To check their findings with respect to galvanized steel and to determine these optimum settings for the different zinc coat thicknesses to be used, tests were run at constant temperatures of 76, 35, 15 and −5°F. while weld time was varied from 3 to 9 cycles and weld current from 55 to 100% heat. Three welds were made at each setting so that an average strength would be obtained. The specimens were then tested to destruction and the ultimate strength, indentation and type of failure were recorded.

These results were plotted as weld strength against percent heat for each weld time, coolant temperature and coating thickness. A typical curve of this series (see Fig. 16) shows the weld strength of medium coated steel for various welding conditions at a coolant temperature of −5°F. All welds were studied for indentation, appearance and type of failure, and the optimum condition selected was determined by the strongest weld that had no burned surface or excessive indentation. These settings are shown in the following table.

It is interesting to note that the optimum welder setting for a given coating is not affected by electrode temperature. As an illustration of this fact, coolant

Coating	Coolant temperature, °F.	Weld time, cycles	Weld current, % heat	Strength, lb.
Light	76	7	80	1200
	35	7	80	1190
	15	7	80	1160
	−5	7	80	1180
Medium	76	7	90	1220
	35	7	90	1150
	15	7	90	1180
	−5	7	90	1170
Heavy	76	7	95	1200
	35	7	95	1080
	15	7	95	1060
	−5	7	95	1050

temperature was plotted against ultimate strength for all weld settings and coatings. Figure 17 shows the strength obtained for various welding conditions on the light coated steel. This fact could be very useful in setting up welding schedules since previously run test at normal electrode temperatures could be used to set optimum conditions. These tests also verified the findings of Dr. Hensel and his associates[6] that at welding conditions other than optimum the benefits of cold tips are quickly obscured.

The effect of the zinc-coating thickness on the weld strength was shown by plotting coat thickness against ultimate strength for various welder settings and tip temperatures. A typical curve shown in Fig. 18 illustrates the general trend found. While the coolant temperature in this case was −5°F., the slope and position of the curves remained about the same for all temperature settings. These curves show that the effect of coat thickness is independent of electrode temperature; as coat thickness increases, weld strength decreases.

A possible explanation for this decrease in strength is as follows. As soon as current flows, the zinc coating melts forming a pool against the electrode and reducing contact resistance and, therefore, heat generated in the weld. To make up for this loss, weld time or current must be increased as coat thickness increases. This reasoning is substantiated by the fact that the effect of coat thickness increases as the weld time and current are

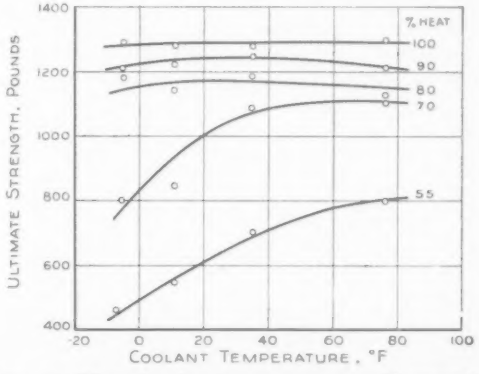


Fig. 17 Effect of coolant temperature on weld strength for various welding conditions on light coated steel

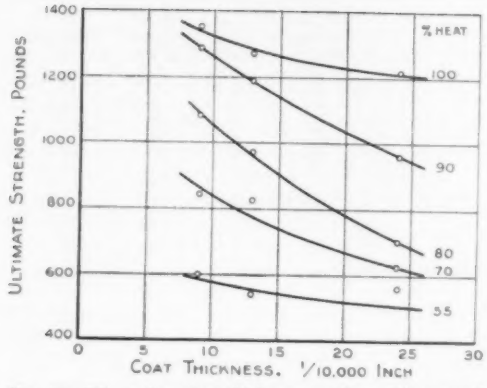


Fig. 18 Effect of coating thickness on the weld strength for various welding conditions at a coolant temperature of −5°F.

decreased. The heat loss at the pool of zinc becomes a larger percentage of the total heat.

In order to study the effects of tip coolant temperatures on weld strength without including the effects of tip wear, a run was made at optimum weld settings for each coat thickness. Three welds were made at each setting, and the temperature and average strength were used in plotting the curve. Temperatures were from 0 to 80°F. at 10° increments and were maintained to plus or minus 1°F.

These results were plotted as ultimate strength against tip temperature for each coating thickness as shown in Fig. 19. The curves show that there is a very slight increase in strength as the tip temperature decreases. To make sure that this effect was due to cool tips and not a tip wear effect, a duplicate run was made starting at 76°F. and going down. These tests duplicated the results of the first and confirmed the 10% strength increase when tip temperatures were varied from 76 to 1°F.

This increase was to be expected for two reasons. First, electrical resistance of copper decreases as temperature decreases thereby reducing electrode heat loss, putting it into the weld. Secondly, the tendency toward flashing and burning welds was less at low electrode temperatures, resulting in less weld porosity, crackage and better quality. Also, electrode mechanical

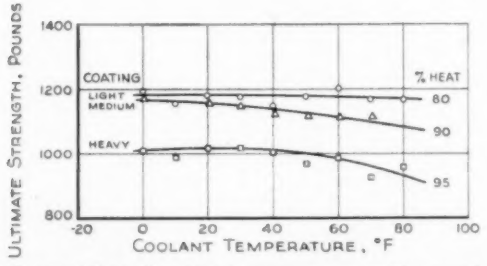


Fig. 19 Effect of coolant temperature on weld strength for each coating thickness

strength increases as temperature decreases. This means less deformation, more correct densities and better welds.

In view of the experimental evidence that the zinc coat was going into the weld, attempts were made to find structural changes under high magnification. Welds were made at various temperatures from 0 to 76°F. They were then cut in half, polished, etched and studied for grain structure changes. The results were disappointing since no etch was found that would show any inclusions or structural changes. It is felt that the development of some etch that would show the structural change would be beneficial to a study of this type because the increased number of weld failures around the weld nugget indicate that there is more zinc inclusion in the weld as tip temperature is reduced. If this is true, then very low tip temperatures could be detrimental on heavily coated sheets because of brittleness.

Studies of the effect of tip temperature on indentation were not satisfactory because the zinc often stuck to the electrodes giving surface irregularities of the magnitude of the indentation in many cases. However, a general tendency could be observed indicating that indentation decreases as tip temperature decreases, but it is not expected that full strength welds can be made without disturbing the zinc coating. Half strength welds can be made at reduced current settings that give only minor surface disturbance. For example: With 0°F. tip temperature and a medium coating of zinc, welds made at 7 cycles and 60% heat give 600 lb. strength and fail in shear, but have only 0.005 in. indentation.

The increased tip life gained by using refrigerated electrode tips in welding aluminum was the main reason for their success in production welding and it was hoped that a corresponding gain could be obtained when welding galvanized steel. Runs of 300 welds were made at each of four tip coolant temperatures ranging from −5 to 76°F. and tendencies of the electrodes to stick, pick up zinc, flash or burn were observed and recorded. At the end of the run, the tips were removed and photographed and a hardness traverse was run across each tip face. The appearance of the tips was very similar. This, however, was felt to be no indication because a thin coat of zinc looks the same as a thick one and alloying under the coat is not visible. When the coatings were removed in refacing the tips, the ones formed during the low temperature runs were found to be very much thinner than those formed during the welding at normal temperature. The flashing and sticking tendencies were materially reduced by the low tip temperature.

CONCLUSIONS ON USE OF REFRIGERATED COOLANT

1. Optimum welding conditions for a galvanized sheet of a given thickness and coating need not be varied for different coolant temperatures.

2. Welding at conditions other than optimum

quickly obscures the benefits of refrigerated electrode tips.

3. At optimum conditions only minor increases in weld strength may be attained.

4. Indentation decreases and weld appearance improves as the tip temperature decreases.

5. The effect of coating thickness is the same at low temperatures as at high temperatures; increased coat thickness reduces weld strength and necessitates increased welding time and current.

6. Electrode tip life is definitely benefited by refrigerating the electrodes. Exactly how much benefit may be obtained for production use is not known and is suggested as a subject for future work.

7. It is felt that the application of refrigeration to tip cooling in galvanized steel work is not too practical because: (*a*) the strength increase is negligible; (*b*) installation and maintenance costs are considerably higher than for normal operation and (*c*) there is considerable delay each time the welder is started to get temperatures down. However, refrigeration might be justified if: (*a*) the tips used were of unusual design and expensive to obtain and recondition, and (*b*) unusually high welding speed was necessary.

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Pearlitic Structure Effect on Brittle Transition Temperature

Discussion by Richard H. Raring

Additional data from the M.I.T. slow-bend test are always very interesting because of the unique control of the conditions of test and the excellent correlation that has been repeatedly demonstrated between experimental results and the theoretical exponential equation relating strain rate and transition temperature.

MacGregor and Grossman[1] have previously demonstrated that results from the M.I.T. slow-bend test can be successfully extrapolated to strain rates occurring in the conventional Charpy "impact" test, and that transition temperatures thus estimated fall at the upper "knee" of the familiar Charpy energy-temperature curve. It should be noted that in the tests reported by reference 1 the conditions of restraint (notch geometry) differed from those of the paper being discussed; consequently, the transition temperature predicted by extrapolation of the results of the latter paper should not necessarily also fall at the upper "knee" of the Charpy curve.

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The paper by Nicholas Grossman was published in the June 1949 WELDING JOURNAL, Research Suppl., pp. 265-s to 269-s.

1. MacGregor and Grossman: "A Comparison of the Brittle Transition Temperature as Determined by the Charpy Impact and the MIT Slow Bend Tests," THE WELDING JOURNAL, **27** (1) pp 16-s to 19-s, Jan. 1948.

In the paper, a conflict appears to exist between the data of Table 2 and three of the high strain-rate points as plotted in Fig. 4; the ordinates of the higher points on curves D, C and E should be interchanged to agree with the tabulated data. If these changes are made, the slopes of the curves are altered somewhat, as shown by Fig. 1 below. In this figure, three more cycles are added to the axis of ordinates in order to permit extrapolation of the curves to deflection rates of the order of the conventional Charpy test.

It is disappointing to find that the extrapolation predicts an unexpected and unlikely conclusion, viz., at Charpy deflection rates, Specimen E with a fine grain size and fine pearlite spacing will have the highest transition temperature, while Specimen B with a coarse grain size and coarse pearlite spacing will have next to lowest transition temperature; in fact, as is evident from Fig. 1, at all deflection rates greater than approximately 300 in./sec. Specimen B will have the lowest transition temperature.

The transition temperatures at Charpy deflection rates as predicted by the extrapolation in Fig. 1 are as follows:

Transition Temperatures at 210 in./sec. (from Fig. 1)

Specimen	Description	Trans. temp., °F.
E	Small grains, fine pearlite	+280
C	Large grains, fine pearlite	+240
B	Large grains, coarse pearlite	+194
D	Small grains, coarse pearlite	+185

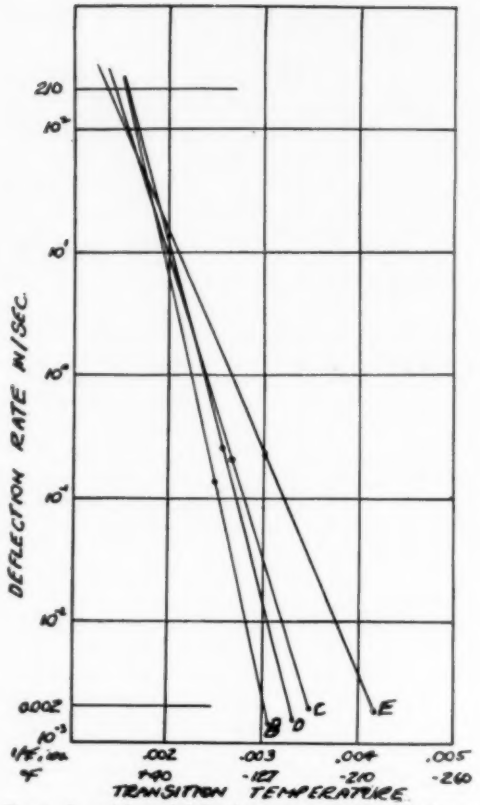

Fig. 1 Logarithm of deflection rate vs. reciprocal of transition temperature

In reviewing reference 1, it was also noticed that the Charpy deflection rate indicated on Fig. 3 of that paper appears to be taken at approximately 120 in./sec. rather than at 210 in./sec., as stated in the text. If this represents an error it would be interesting to determine the transition temperatures at 210 in./sec. and to compare them with those indicated on Fig. 4 of reference 1.

The straight line relationship between the logarithm of the deflection rate and the reciprocal of the testing temperature has been clearly shown for the deflection rates possible in the M.I.T. slow-bend test, but it would seem that further tests are necessary to establish this relationship at the higher, but still relatively low, strain rates of the Charpy "impact" test.

Author's Reply

The author wishes to thank Mr. Raring for his valuable comments and his sustained interest in this Project's activities.

As the discussor points it out, extrapolation of results to Charpy values should not be attempted with the geometries encountered in the present paper. In the article referred to above[1] the *same geometries* were used both in the slow-bend and Charpy tests. This is not the case now!

There is an error in Fig. 4 of the paper being discussed; the shift in curves is so small, however, that it does not invalidate any of the statements made in the paper. As long as the original stipulations of the relation between deflection rate and absolute transition temperature are adhered to, no conflict between the results reported, and previous empirical knowledge is encountered. One of the stipulations is that the transition temperature values should fall *below room temperature*. It is evident that Mr. Raring's extrapolated values are not only well above room temperature, but extend even in the "aging temperature" zone for the steels tested. It is idle speculation to assume the relationship between transition temperature and strain rate in a region where concomitant metallurgical changes take place as well. Since reference was made to a previous paper it may be well in place to quote the paragraph referring to such extrapolated values.[2]

"While previous tests have demonstrated the linearity of curves of the type included in Fig. 3, over the ranges between test points, and the lower strain-rate points were accurately determined, present equipment available did not permit the extrapolation of such curves at intermediate strain rates between those available in the slow-bend test and the Charpy rates. It is always possible that these curves are not strictly linear over the wider temperature ranges included, although the authors feel that the only case open to some question on this source is steel B."

The matter of the selection of Charpy velocities is also discussed under the above reference. Still another important point previously stated may be re-emphasized by quoting from the same paper[2]:

"Since brittle fractures are obtained in the slow-bend test with very low energy levels, caution should be observed not to associate with the predicted slow-bend transition temperatures. . .the high-energy values present on the upper knees of the Charpy "S" curves."

In concluding it may be stated that the most urgently needed information in this field is the quantitative knowledge of the effects of geometries on the transition temperatures. Until such time, however, assumptions have to be employed, which may or may not prove to be correct in light of future results.

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2. Supplementary statement on "A Comparison of the Brittle Transition Temperatures as Determined by the Charpy Impact and M.I.T. Slow-Bend Tests," by C. W. MacGregor and N. Grossman, THE WELDING JOURNAL, 27 (3), Research Suppl., 159-s to 160-s. March 1948.

Strain Aging in Welding Structural Steel

Part 2: As-rolled, rimmed steel. Sensitivity of strain-aged specimens of base and weld metal is indicated and the effects of a thermal (stress-relief) treatment are noted. This treatment may, however, cause temper brittleness

by W. H. Bruckner and S. W. Sandberg

Abstract

Tests were made of 1/2-in. thick rolled plates of A.S.T.M. A70-44 steel of firebox, rimmed-steel grade. Welds were made in the plates with E6010 electrode. Strain-aging tests were made with taper-drawn, work-brittleness bars of plate and weld deposit cold drawn to provide a strain gradient of 0 to 10% reduction of area. Hardness tests were made to follow changes in hardness with time and temperature for definite strain levels. Charpy V-notch impact tests were made over a range of temperature, to determine notch sensitivity and transition temperatures of base plate and weld deposit in original condition, strain aged and in thermally stress-relieved condition. The weld deposit was laid down in such a manner as to fully recrystallize all previously deposited weld metal. Under the conditions of testing, positive indications of sensitivity to strain aging were observed for the base metal for strains as low as 0.5% elongation in tension. For the weld metal strain aging was not indicated for strains of less than 2% elongation in tension. The weld metal appeared to be sensitive to quench aging and both base and weld metals upon thermally stress relieving had a higher transition temperature in impact than in the original condition. The latter observation suggested the possibility of temper brittleness resulting from heating the materials to 1100° F. and cooling slowly for stress relief.

INTRODUCTION

THE present report concerns a study that was made of the susceptibility to strain aging of 1/2-in. thick rolled plates of A.S.T.M. A70-44 steel which was of firebox, rimmed-steel grade and of the weld metal deposited in this plate with E6010 electrode. The study was carried out in practically the same manner as is described in a prior publication by Bruckner and Ellis.* The prior study indicated that for the semikilled steel tested neither the base metal nor the weld-deposited metal were susceptible to embrittlement due to strain aging for strain levels of 2% elongation or less in tension.

The present report of the data obtained for the A.S.T.M. A70-44 steel is of interest to the welding profession since the material, rimmed steel, is known to be susceptible to strain aging and it was not known previously to what degree this sensitivity to age after straining would be carried over into the weld deposit made in such steel.

The relative merits or disadvantages of performing mechanical or thermal stress-relief operations on welded

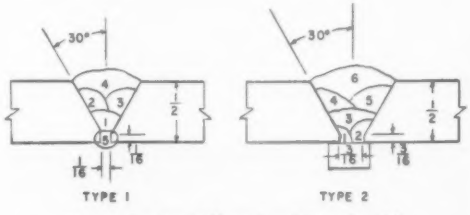

Fig. 1 Design of Type 1 and Type 2 welds

Pass	*Electrode Diameter, in.*	*Current amp.*	*Remarks*
1 Type 1	5/32	160	E6010 Electrode
1 Type 2	5/32	140	d.-c. rev. polarity welded continuously while clamped to bench, cooled in clamped position.
2	3/16	200	
3	3/16	200	
4	3/16	200	
5	3/16	200	
6	3/16	200	

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The junior author conducted the tests as a thesis assignment under the direction of the senior author to partially fulfill the requirements for the degree of master of science in the Dept. of Mining and Metallurgical Engineering, of which Prof. H. L. Walker is the Head.

Scheduled for presentation at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

* THE WELDING JOURNAL, **27** (9), Research Suppl., 441-s to 447-s (1948).

joints in low-carbon structural steels were also unknown prior to undertaking the research program.

ACKNOWLEDGMENT

The steel plate used for the investigation was a part of the stock left over from a program of tests conducted in the department of civil engineering to determine the fatigue strength of butt welds. The material was made available by Prof. W. M. Wilson, research professor of structural engineering in the department of civil engineering. Prof. W. H. Munse and Dr. R. A. Hechtman of the same department also contributed time and effort in scheduling the welding and in mechanical stress relieving of the individual specimens.

MATERIALS AND METHODS

The chemical and physical properties of the $^1/_2$-in. thick plate of A.S.T.M. A70-44 steel are given in Table 1. The sensitivity of the base metal to strain aging was determined by means of (*a*) Vickers hardness tests made on sections cut from a tensile bar which was strained to 2% elongation in the direction of rolling, (*b*) Izod notch, impact tests made on work-brittleness bars which were cold drawn to effect a strain gradient of 0 to 10% reduction of area and (*c*) Charpy V-notch impact tests of specimens taken from the base plate subsequent to subjecting the plate to a tensile strain of 0.25% which is the average amount of strain associated with mechanical stress-relieving methods. Parallel tests (*a*), (*b*) and (*c*) above, were made of the weld-deposited metal.

Table 1—Chemical and Physical Properties of Base Metal

Element	%
Carbon	0.23
Manganese	0.55
Phosphorus	0.016
Sulphur	0.028

Yield point, p.s.i.	35,600
Tensile strength, p.s.i.	58,100
Elongation (8 in.), %	31.5
Reduction of area, %	56.0

Figure 1 shows the design of the Type 1 and Type 2 welded joints and the sequence of welding. The Type 2 welds were designed to give a larger amount of weld-deposited metal than Type 1. The larger weld deposit was required for all-weld-metal tests (*a*) and (*b*) paralleling the tests of base metal for sensitivity to strain aging. The Type 1 welds were used as a source of the Charpy V-notch specimens for parallel tests (*c*). The manner in which the specimens for Charpy impact tests of weld metal were notched is shown in Fig. 2.

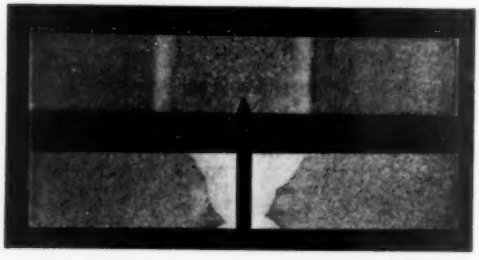

Fig. 2 Location of V-notch in Charpy impact specimens of weld deposit

Table 2—Schedule of Tests

Material	*Condition*	*Tests made*
	Base metal	
Tensile bars	As-strained 2%	Vickers hardness vs. time and temperature
Izod bars	As-rolled and processed for work-brittleness test	Control specimen; work-brittleness tests 0 to 1.8% strain and 0 to 8.3% strain, both as-strained and as-aged at 212 or 300° F.
Plate *A*	As-rolled	Charpy impact tests; transverse to rolling direction; Vickers hardness at 72° F.
Plate *B*	As-rolled	Charpy impact tests, parallel to rolling direction; Vickers hardness at 72° F.
Plate *D*	Thermally stress relieved	Charpy impact tests, transverse to rolling direction; Vickers hardness at 72° F.
Plate *K*	Mechanically stress relieved	Charpy impact tests, transverse to rolling direction; Vickers hardness vs. time at 72° F.
Plate *J*	Mechanically stress relieved	Charpy impact tests, transverse to rolling direction after aging 110 days at 72° F., and then $^1/_2$ hr. at 300° F., Vickers hardness vs. time at 72° F
Plate *L*	Mechanically stress relieved	Charpy impact tests, transverse to rolling direction after aging 110 days at 72° F.; Vickers hardness vs. time at 72° F.
	Type 2 welds	
All weld metal tensile bars	As-welded and strained 2%	Vickers hardness vs. aging time and temperature
Izod bars	As-welded	Control specimen, work-brittleness tests 0 to 1.8% strain and 0 to 8.3% strain, both as-strained and as-aged at 212 or 300° F.
	Type 1 welds	
Plate *C*	As-welded	Charpy impact tests after aging 108 days; Vickers hardness vs. time at 72° F.
Plate *E*	Thermally stress relieved	Charpy impact tests; Vickers hardness at 72° F.
Plate *F*	Mechanically stress relieved	Charpy impact tests as strained; Vickers hardness vs. time at 72° F.
Plate *G*	Mechanically stress relieved	Charpy impact tests after aging 110 days at 72° F.; Vickers hardness vs. time at 72° F.
Plate *H*	Mechanically stress relieved	Charpy impact tests after aging 110 days at 72° F.; Vickers hardness vs. time at 72° F.

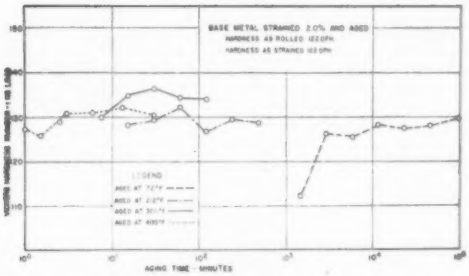

Fig. 3 Results of hardness tests of strained base metal, aged at various temperatures

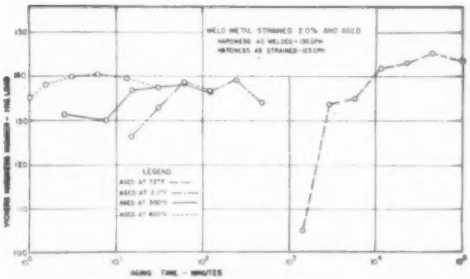

Fig. 4 Results of hardness tests of strained all-weld metal, aged at various temperatures

Table 2 gives a schedule of all tests which were made of the base metal and weld metal. The thermal stress-relief treatment consisted of heating the material to 1100° F. at a rate of about 100° F. per hour, holding for ½ hr. and cooling at the same rate to 650° F. The cooling rate thereafter was more rapid, being accomplished with the furnace door left open. The mechanical stress relief of the welds was accomplished by means of a tensile stress applied in the direction of the weld to effect an average permanent strain of approximately 0.25%. Mechanical stress relief of the base plate was effected in the same manner with the stress in the rolling direction. For the Izod impact tests, tapered work-brittleness bars were drawn through a die to provide a strain gradient. For the initial Izod impact tests of base and weld metal the tapered bars were machined with a slight taper so as to provide a strain gradient after cold-drawing of 0 to 1.8% reduction of area. Further tests were then made with tapered bars in which the strain gradient after cold drawing was 0 to 8.3% reduction of area.

DATA OBTAINED

As shown in the schedule of tests made, Table 2, Vickers hardness tests were made of the base and weld metal which had been strained 2% in tension. These data are given in Figs. 3 and 4, respectively, for the base and weld metal. The data for control tests, Table 2, of the change in hardness with time of the base and weld metal subsequent to mechanical stress relief are shown in Fig. 5. Plates *J*, *L* and *K* were base-metal specimens and plates *G*, *H* and *F* were welded specimens. For comparison, a hardness control test of the as-welded, unstrained specimen is also shown in Fig. 5. The control tests gave an indication of the strain-aging behavior from the time the specimens were strained up to the time, 110 days, that the Charpy impact tests were made.

The results of Izod notch impact tests made on bars of cold-drawn base metal and weld metal are shown in Fig. 6 for bars tapered to provide a strain gradient of 0 to 1.8% reduction of area. The points on the curves show the per cent reduction of area in cold drawing suffered by the bars at the point where the impact notch was machined. The curves of Figs. 7 and 8 show, respectively, the results of Izod, notch-impact tests made on base and weld metal bars cold drawn to provide a strain gradient of 0 to 8.3% reduction of area.

The results of the Charpy V-notch impact tests are summarized in Figs. 9 and 10 which give the energy vs. temperature curves drawn through the set of points obtained for each separate test series. The data from which the curves of Figs. 9 and 10 were obtained are shown in the curves of Figs. 12 to 21.

The transition temperatures which were estimated from the data for the Charpy V-notch impact tests are given in Table 3. Three criteria for the transition tem-

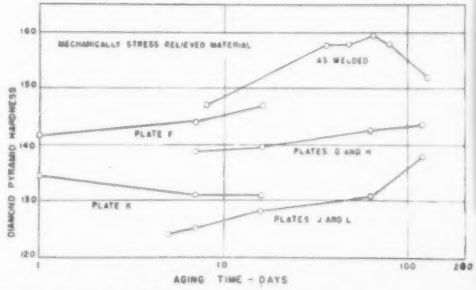

Fig. 5 Results of hardness control tests made on mechanically stress-relieved base and weld metal, compared with the weld metal in the as-welded condition. All specimens aged at room temperature

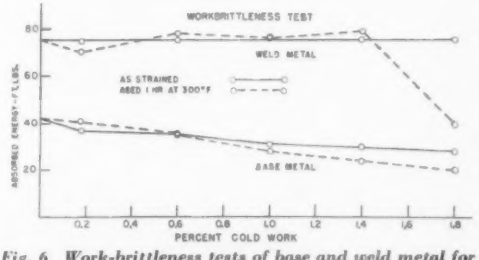

Fig. 6 Work-brittleness tests of base and weld metal for strain gradient of 0 to 1.8% reduction of area

perature were used, e.g.: (*a*) The temperature corresponding to one-half of the maximum energy absorption for the curves of Figs. 11 to 21, (*b*) the temperature at which the first evidence of brittleness was observed in the fracture and (*c*) the temperature halfway between maximum and minimum energy absorption.

Table 3—Estimated Transition Temperatures in ° F. for Charpy, V-Notch Impact Tests of Base and Weld Metal

Treatment	*One-half maximum energy level*	ΔT*	*First evidence of brittleness*	*Temperature halfway between maximum and minimum energy*
	Base metal			
Parallel to rolling direction	75	−10	160	95
Transverse to rolling direction†	85	0	175	90
Thermally stress relieved	95	10	190	110
Mechanically stress relieved	80	5	160	80
Mechanically stress relieved, aged at R. T. and 300° F.	95	10	200	100
Mechanically stress relieved at R. T.	95	10	205	110
	Weld metal			
As-Welded	−10	0	70	0
Thermally stress relieved	20	30	90	10
Mechanically stress relieved	0	10	105	40
Mechanically stress relieved, aged at R. T. and at 300° F.	−10	0	40	10
Mechanically stress relieved, aged at R. T.	−15	−5	45	−5

* ΔT is the differential between a particular test and the control test.

† Control or base line value.

DISCUSSION OF THE DATA

The individual hardness tests which were made to determine the onset and progress of strain aging showed considerable scatter both for base-metal and weld-metal specimens. It was therefore necessary to treat the hardness data statistically in order to determine significant changes in hardness which might indicate the existence of an aging process. As shown in Fig. 3, for the base metal, the most significant increase in hardness occurred upon aging, at 300° F., the material which had been strained 2% in tension. As shown in Fig. 4, for the weld metal, the most significant increase in hardness occurred at room temperature in deposited metal which had been strained 2% in tension. However, the hardness control data for the as-welded, unstrained deposited metal shown in Fig. 5 indicated that there was

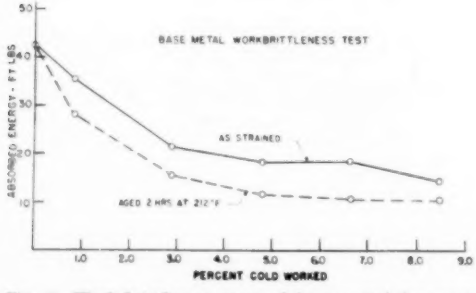

Fig. 7 Work-brittleness tests of base metal for strain gradient of 0 to 10% reduction of area

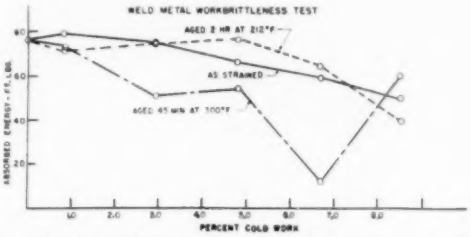
WELD METAL WORKBRITTLENESS TEST
AGED 2 HR AT 212°F
AS STRAINED
AGED 45 MIN AT 300°F
ABSORBED ENERGY - FT. LBS.
PERCENT COLD WORK

Fig. 8 Work-brittleness tests of weld metal for strain gradient of 0 to 10% reduction of area

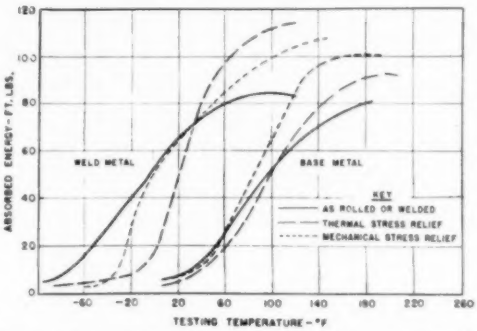

Fig. 9 Charpy V-notch impact tests of base and weld metal in original condition and as-stress relieved

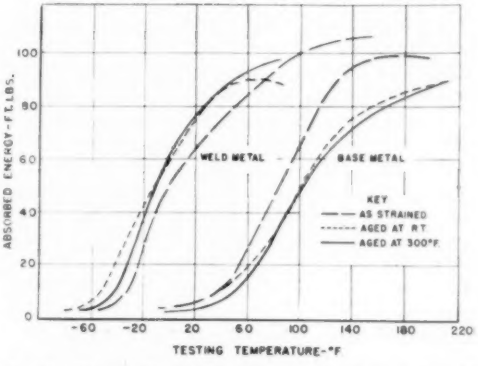

Fig. 10 Charpy V-notch impact tests of base and weld metal in as-strained and as-strained and aged

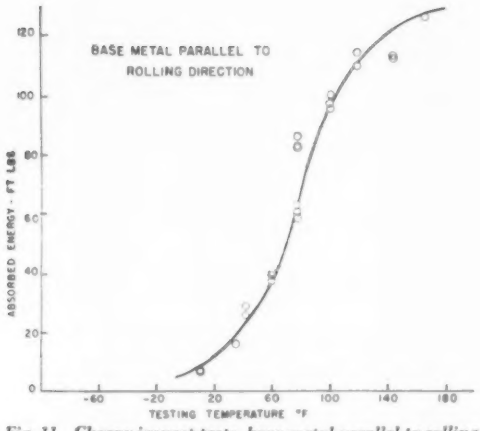

Fig. 11 Charpy impact tests, base metal parallel to rolling direction

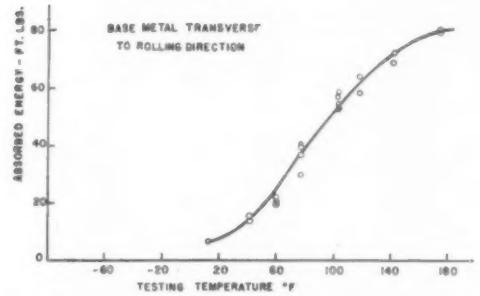

Fig. 12 Charpy impact tests, base metal transverse to rolling direction

a relatively rapid rise to a maximum hardness value which then decreased. This behavior is characteristic of quench aging in that the rise in hardness to a maximum value is not maintained for long periods of time as is the maximum hardness due to strain aging. If this distinction is not recognized the increase in hardness of the as-welded, unstrained metal might otherwise be attributed to an aging reaction resulting from the plastic strain incident to the stresses imposed by the heating and cooling cycles in welding. It therefore appears that the initial rise in hardness shown in Fig. 4 of the strained, weld-deposited metal, aged at room temperature, may be entirely due to quench aging rather than to strain aging. This is also borne out by the Charpy impact data to be discussed later.

The changes in hardness of the mechanically stress-relieved base and weld metal shown in Fig. 5 indicated that the base metal plates *J* and *L* had strain aged at room temperature to a significant extent after undergoing the small, 0.25% plastic strain of mechanical stress relief. The welded plates *G* and *H* did not show a significantly large increase in hardness, moreover quench aging may have been responsible for the slight change in hardness which was noted.

The results of work-brittleness tests are shown in Figs. 6, 7 and 8. All of the tests were made at one temperature which was approximately 75° F., thus there is no indication of the temperature at which a transition from ductile to brittle behavior occurs. However the Charpy impact data which are discussed later indicated that 75° F. is above the transition temperature of the weld metal and is in or below the transition temperature range of the base metal for the Charpy V-notch type specimens.

For small strains the data for the weld metal shown in Fig. 6 are not entirely consistent with those shown in Fig. 8, however the work-brittleness data for the base metal are consistent in the trends shown in Figs. 6 and 7. Due to the consistency of the latter data there is positive evidence of the existence of strain aging of the base metal as a cause of the embrittlement indicated. For the weld metal there appears to be some indication of embrittlement due to aging at 300° F. at values of strain greater than about 1.5% reduction of area. However the data are not consistent and it is not known how much of the indicated trend can be ascribed to normal scatter, a shift in transition temperature or to

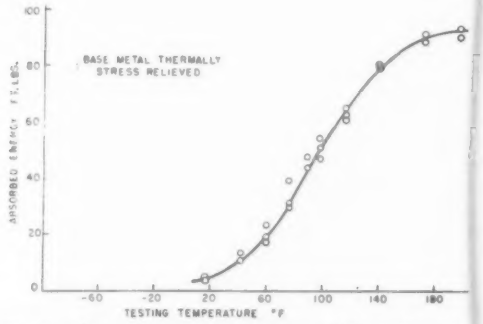

Fig. 13 Charpy impact tests, base metal thermally stress relieved

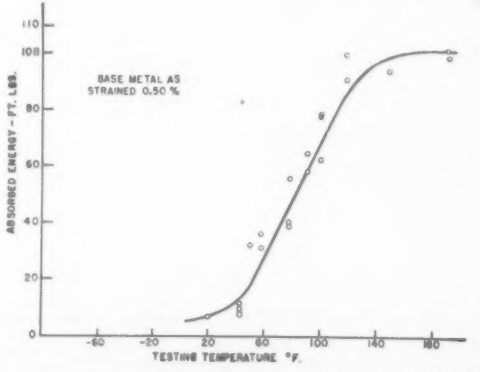

Fig. 14 Charpy impact tests, base metal as-strained 0.50% in tension

an aging reaction. It would appear that more extensive testing would be required to clearly delineate the weld metal behavior. It is clear, however, from the data shown in Figs. 7 and 8 that embrittlement occurred in the base metal and not in the weld metal when the specimens were aged for 2 hr. at 212° F. after straining.

The data from the Charpy V-notch impact tests were more conclusive since it was not only possible to determine energy absorption but also the transition from ductile to brittle behavior. The curves shown in Figs. 9 and 10 summarize the data for the tests made with base- and weld-metal specimens. All the data for the base metal shown in Figs. 9 and 10 were obtained from Charpy impact tests in which the length of the specimens was transverse to the rolling direction. For purposes of comparison, however, one series of test was made with the length of the Charpy impact specimens parallel to the rolling direction; the data for these tests are shown in Fig. 11. A greater absorption of energy and a lower transition temperature are in evidence for the specimens whose length was parallel to the rolling direction than for the specimens whose length was transverse to the rolling direction. The data for the transverse specimens in the as-rolled condition are shown in Fig. 12.

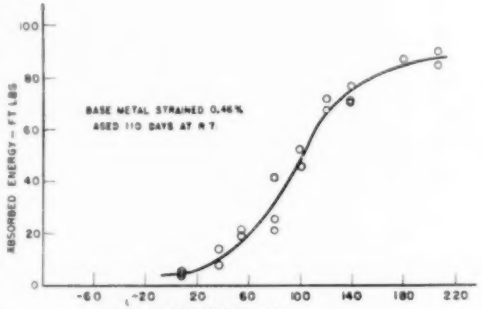

Fig. 15 Charpy impact tests, base metal as-strained 0.46% in tension and aged at room temperature

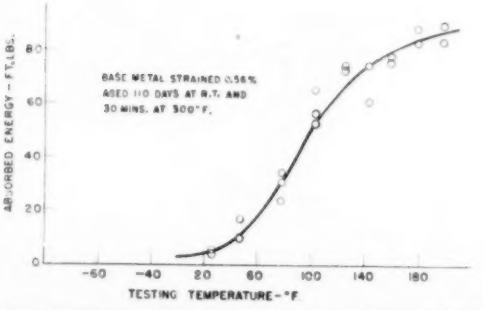

Fig. 16 Charpy impact tests, base metal as-strained 0.56% in tension and aged at room temperature and 300° F.

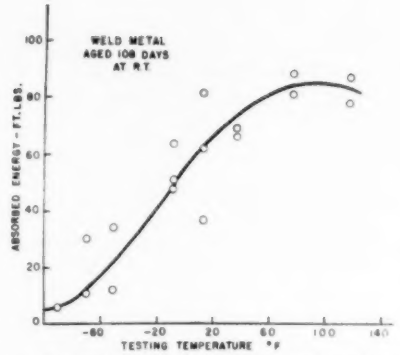

Fig. 17 Charpy impact tests, weld metal aged at room temperature

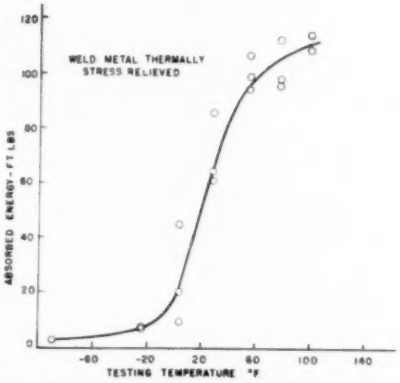

Fig. 18 Charpy impact tests, weld metal thermally stress relieved

For the base metal, mechanical stress relief alone had an insignificant effect upon the behavior in Charpy impact tests. The transition temperature was increased however when aging at 300° F. or at room temperature followed the strain due to mechanical stress relief. The thermal stress relief also had the same effect of increasing the transition temperature although strain was not a factor. It is possible that a temper-brittleness-precipitation on cooling from the thermal stress-relief treatment may have been responsible for the embrittlement.

The weld metal had a transition temperature of −10° F. which is 95° F. below the transition temperature of 85° F. for the original base metal. It is of interest to note that the weld metal deposited in the semikilled steel as previously reported also had the same transition temperature of −10° F. in the as-welded condition. Table 4 compares the data as to transition temperatures for the Charpy, V-notch impact tests made on the rimmed steel with the data previously obtained and published for the semikilled steel. It is evident that in spite of the higher transition temperature of

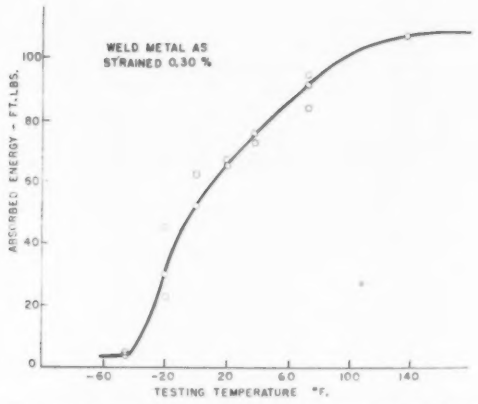

Fig. 19 Charpy impact tests, weld metal as-strained 0.30% in tension

the rimmed-steel base metal the weld deposit is apparently so well protected by the atmosphere and slag produced by the electrode coating that no significant deterioration results. There is however a serious increase of 30° F. in the transition temperature of the weld deposit in the rimmed steel following thermal stress relief. The increase in transition temperature due to thermal stress relief is quite general for weld metal and base metal of the two different steels as shown in Table 4. Since strain aging is not a factor it appears probable that temper brittleness may be the factor involved; the weld metal deposited in the rimmed steel is more susceptible to temper embrittlement than the weld deposit in the semikilled steel.

For the weld metal, mechanical stress relief appears to be preferable to thermal stress relief, at least with respect to obtaining a favorable lower transition temperature for the mechanical stress relief. However, for the rimmed-steel base metal the tendency toward embrittlement due to strain aging after undergoing the slight strain involved in mechanical stress relief gives no advantage for either mechanical or thermal stress relief. The only advantage generally apparent after thermal stress relief was the slightly greater maximum absorption of energy due to the partial spheroidization of the carbide lamellae during heat treatment.

It should be noted that the transition temperature of the weld metal deposited in the rimmed steel is so much lower (by 95° F.) than the transition temperature of the base metal as to take the weld metal out of consideration as a critical factor in a joint made in a rimmed steel of the type used in these studies. The weld metal to which these remarks apply was exclusively the recrystallized, fine grain portion of the deposit thus excluding the as-cast, columnar structure from any part of the test program.

The hardness tests on base and weld metal subjected to a tensile strain of 2% elongation and the Izod impact test of cold-drawn bars of base and weld metal indicated that the weld metal may be embrittled by strain aging, quench aging or a combination of both when the strain

Table 4—Comparison of Data on the Transition Temperatures for Charpy V-Notch Impact Tests of Semikilled and Rimmed Steel and Welds

(Transition Temperatures Are in° F. and Were Obtained by Considering the Temperature at $^1/_2$ the Maximum Energy)

Treatment	*Semikilled steel*	*Rimmed steel*
Base Metal		
As-rolled	−10	75–85
Thermally stress relieved	−2	95
Mechanically stress relieved	..	80
Mechanically stress relieved and aged at room temperature	0	95
Weld metal		
As-welded	−10	−10
Thermally stress relieved	−5	20
Mechanically stress relieved	..	0
Mechanically stress relieved and aged at room temperature	−28	−15

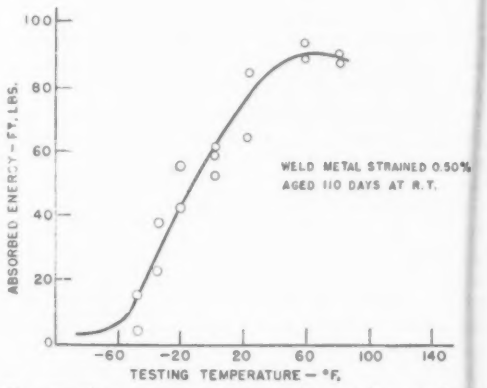

Fig. 20 Charpy impact tests, weld metal as-strained 0.50% in tension and aged at room temperature

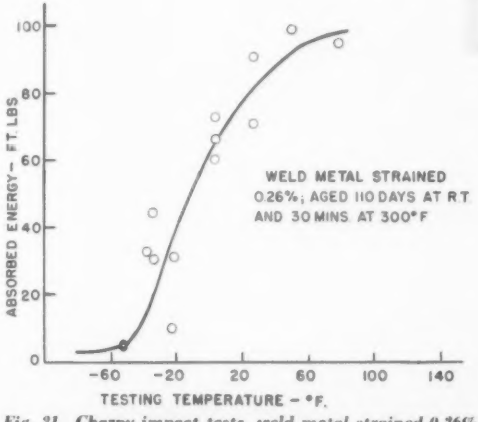

Fig. 21 Charpy impact tests, weld metal strained 0.26% in tension and aged at room temperature and 300° F.

was of the order of or greater than 2% elongation. The similar tests of the base metal confirmed the Charpy impact data in showing that a strain of low order, less than 2% tensile elongation, is sufficient to produce embrittlement due to strain aging.

SUMMARY

The transition temperature of Charpy V-notch impact tests of E6010 weld metal deposited in A.S.T.M. A70-44 steel was found to be 95° F. lower than that of the base metal. Due to the large difference in the transition temperatures it was concluded that the impact properties of the base metal were of prime consideration and that the impact properties of the weld metal were not critical. However, all of the tests of the weld metal were confined to the recrystallized portions of the deposit and excluded the columnar, as-cast sructure.

The rimmed-steel base metal was found to be sensitive to strain aging. The sensitivity was manifested at low strain levels and increased with the strain level. The low plastic strain level of 0.25% elongation associated with mechanical stress relief was sufficient after aging at room temperature to increase the transition temperature by a significant amount.

The recrystallized weld metal was not sensitive to strain aging at low strain levels. However, aging was manifested by the as-welded, weld deposit. The aging reaction was followed by means of hardness tests and it was observed that maximum hardness levels were not sustained. It was concluded therefore that quench aging rather than strain aging was the cause of the changes observed in the as-welded deposit. At higher levels of strain, considerably greater than the 0.25% plastic elongation associated with mechanical stress relief, the weld metal exhibited a limited amount of embrittlement due to strain aging.

The most marked change in the weld-deposited metal was brought about by thermal stress relief which increased the transition temperature by 30° F. There was an increase in transition temperature due to thermal stress relief for the rimmed-steel base metal and for the semikilled steel previously reported but the changes were of lesser extent than for the weld metal deposited in the rimmed steel. The increase in the transition temperature was believed to be due to temper brittleness which in turn is believed to be caused by grain boundary precipitation during the cooling period after heating for the relief of stress.

It would appear that for the rimmed steel tested the use of mechanical rather than thermal methods of stress relief may have some advantage. However, even after thermal stress relief the transition temperature of the weld deposit was still 75° F. below that of the base metal in the thermally stress-relieved condition.

Atlas of Isothermal Transformation Diagrams

Control over the results of heat treatment of steel has been extended in recent years by the study of "S-curves" or isothermal transformation diagrams.

These curves show what happens to the structure of a particular steel when it is held at a certain temperature after rapid cooling from above the critical temperature, which is usually in the range of 700 to 800° C. They show the varying effects on the structure of holding or soaking at various temperatures for different periods of time. Below a temperature known as the MS point the martensitic transformation is instantaneous, although the degree of transformation can be controlled by suitable choice of quenching temperature. All transformation temperatures vary according to the composition of the steel.

For example, if a 3% nickel steel (En 21) is quickly cooled from above 700 to about 400° C. and held at that temperature, transformation of the austenite begins after about 15 sec., and the amount transformed is, respectively, 10, 50, 90, and 100% after about 30, 50, 100 and 400 sec. But if the soaking temperature is 350° C. transformations begins after 35 sec., and the corresponding periods for 10, 50, 90 and 100% are about 75, 150, 300 and 900 sec. The MS point for this steel is 310° C.

For this particular steel, numbers of detailed observations have been made at 13 temperatures, ranging between 350 and 700° C. The S-curves plotted from these observations correspond to the five stages of transformation mentioned above. They show the time of soaking required at each temperature on the curves for each stage to be reached.

The first authoritative published collection of S-curves for the main types of wrought steel in current use in this country is contained in the "Atlas of Isothermal Transformation Diagrams" now issued by the Iron and Steel Institute as Special Report No. 40.

The data have been collected by the Thermal Treatment Subcommittee of the British Iron and Steel Research Assn., and represent the results of collaborative work by a number of industrial laboratories. The Atlas contains S-curves for 24 En steels of the British Standards Institution's En series detailed in B.S. 970: En 12 to 19, 21, 23 to 26, 28, 30, 31, 40, 42, 44, 45, 47, 56, 100 and 110. Each diagram is accompanied by a data sheet which records the compositions of the steel, its previous treatment, the hardness of the transformation products obtained at various temperatures, photomicrographs and general comments which include reference to the hardenability of the steel.

The text of the report outlines the principles underlying the construction of isothermal transformation diagrams and the experimental procedure used for the determination of the curves, and discusses the results and their application.

The report points out that it is the main purpose of isothermal transformation diagrams to provide a basis for appreciating the behavior of steels when quenched in sections which do not harden completely, rather than to give data for the design of heat-treatment schedules. They are, in fact, often regarded as offering no more than a general indication of the transformation behavior of a given steel, but the special care is taken in this investigation to check the representative nature of the steels and the confirmation of the curves by independent laboratories justifies their more confident use.

The report is bound in stiff covers and the diagrams are printed on good quality paper suitable for penciling in additional curves. Curves traced on transparent isothermal transformation test charts may be conveniently superimposed on the printed diagrams. Suitable charts have been designed by the Thermal Treatment Subcommittee and are available from Pawson and Brailsford, Ltd., Mulberry St., Sheffield. The report is published by the Iron and Steel Institute, 4, Grosvenor Gardens, London, S. W. 1., price 15/- to members and 25/- to nonmembers.

Gas Evolution from Weld Metal Deposits

The importance of measuring rates and quantities of hydrogen evolved from weld deposits is discussed. Improved methods for their determination are proposed

by I. L. Stern, J. Kalinsky and E. A. Fenton

INTRODUCTION

THE important role that hydrogen plays in influencing the properties of weld deposits is evidenced by the frequent reference to this subject in current technical literature. It has been shown that there is a relationship between hydrogen content and fisheyes,[1] flakes,[2] underbead cracking[3] and lowered ductility of weld deposits.[4] In addition it has been demonstrated[5] that hydrogen may be responsible for the lack of adherence which is frequently encountered in porcelainizing over welds shortly after their deposition.

For many years the formation of cracks in the heat-affected zone adjacent to the weld has been the subject of widespread investigation. Most of the research work considered such factors as thermal stresses, stresses accompanying phase changes, and reaction stresses due to external restraint of the welded joint. In 1940 Zappfe and Sims[5] discussed the role of hydrogen in producing defects in weld metal. Since that time, many investigators[6–16] have demonstrated the relationship between hydrogen and cold cracking. The hydrogen theory of cold cracking is now widely accepted, although the exact mechanism of crack formation is not completely understood.

A summary of the most prevalent theory follows:[2,3,4,8] Although steel is impermeable to molecular hydrogen, it exhibits a variable permeability for atomic hydrogen. Hydrogen-bearing compounds in the electrode coating are dissociated in the arc, releasing atomic hydrogen which is absorbed by the molten weld metal. After the molten weld metal solidifies, it passes from the γ-phase (austenite) to the α - phase (ferrite). The adjacent base metal, which had been heated above the upper critical temperature, also cools from the austenitic to the ferritic phase. Since the solubility of hydrogen in austenite is much greater than in ferrite, appreciable quantities of hydrogen are rejected, as the latter phase forms. During cooling, the diffusion rate of hydrogen through the metal, as well as the ductility of the metal, is decreasing, while tensile strength is increasing. The combination of all these factors may possibly lead to the formation of minute pockets of high-pressure molecular hydrogen within the cooling metal. These high-pressure pockets in combination with the stress accompanying the cooling of the metal may be sufficient to cause rupture. In cases of underbead cracking, the tendency toward cracking is accentuated by the volume changes accompanying the formation of martensite which forms brittle areas with localized stress concentrations. In cases of cracking of the weld bead itself, interdendritic microfissures[19] have been observed in a ferritic matrix. The lack of adherence frequently encountered in porcelainizing after welding is caused by the diffusion of hydrogen to the metal surface beneath the porcelain, and is evidenced by the clean, scale-free steel surface at the interface.

It is apparent from the above that information relative to the amount of hydrogen which would be absorbed in weld deposits as well as its rate of evolution would be of primary importance. Low- or high-temperature hot-extraction methods of measurement under vacuum have been described throughout the literature. However, these methods require elaborate apparatus and highly trained personnel for their operation. The simplest method for measurement of hydrogen evolution is described in this paper as Method 1. The various deficiencies of this method are indicated under "Discussion of Results." Methods 2 to 4 which were developed by the authors are not intended to replace the hot-extraction methods. However, it is believed that the proposed methods offer a means of obtaining a reasonably accurate measure of evolution rates and quantities without requiring the elaborate and expensive apparatus of the other methods.

I. L. Stern and **E. A. Fenton** are Welding Engineers and **J. Kalinsky** is Chemical Engineer at Material Laboratory, New York Naval Shipyard, Brooklyn, N. Y.

The data reported in this paper have been collected for a thesis submitted in partial fulfillment of the requirements for the degree of Master of Metallurgical Engineering at the Polytechnic Institute of Brooklyn by E. A. Fenton. The opinions expressed herein are those of the authors and do not necessarily represent the opinions of the Navy Department.

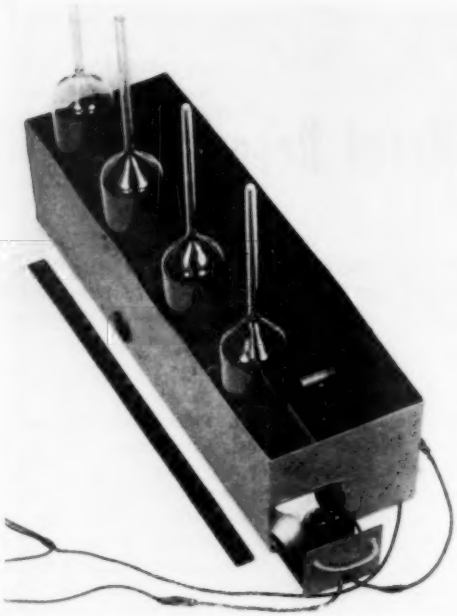

Fig. 1 Eudiometers and gas-collecting liquid reservoir—Method 1

DESCRIPTION OF METHODS FOR DETERMINING HYDROGEN EVOLUTION

Method 1

This method (see Fig. 1) is based on the collection of the evolved gas over glycerin. It was incorporated into the Navy Department, Bureau of Ships Specification for low-hydrogen type electrodes[17] and has subsequently been adopted by the A.W.S.-A.S.T.M. Specifications.[18] The test specimen is put into a eudiometer (gas volume measuring) tube, which has previously been completely filled with glycerin. The open bottom of this tube remains below the surface of glycerin in a trough of a glycerin-filled tank while the test piece is inserted into the tube. The tube containing the test specimen is then set in an upright position on a shelf inside the tank. The temperature of the glycerin in the tank is maintained thermostatically at approximately 45° C. (113° F.) by means of three 60-watt bulbs placed outside the tank beneath the shelf. The amount of liberated gas is observed and recorded at desired intervals by reading the volume as shown on the graduated stem of the eudiometer tube. This stem is graduated to 8 cc. in 0.1-cc. divisions.

For all volumes mentioned in this paper, the standard condition represents room temperature (70° F.) and atmospheric pressure (760 mm. Hg).

Method 2

This method is based on the principle that in a closed evacuated system, kept at constant temperature, the change in pressure within the system is directly proportional to the volume of gas evolved into it. The apparatus for this method is essentially identical with that shown in Fig. 3, excluding Part 9.

A. Calibration of Apparatus:

(*a*) The volume of Tube 8, Fig. 3, was determined by filling with water from a 10-cc. burette calibrated in 0.05-cc. graduations.

(*b*) With the water removed from Tube 8, Stopcock 1 was opened and the apparatus was evacuated to 0.1 mm. Hg; Stopcock 1 was then closed. The end of Tube 8 was sealed with a finger tip and Stopcock 1 was momentarily opened and closed, thereby admitting the air of Tube 8 to the entire system. The increase in height of mercury, Column 5, was noted.

(*c*) The volume of air (V_1) introduced at atmospheric pressure (P_1) is equal to the volume of Tube 8. The final pressure (P_2) of the system is equal to the height of the mercury column. Since $P_1V_1 = P_2V_2$ where V_2 is equal to the final volume (volume of chamber plus volume of Tube 8), therefore

$$V_2 = \frac{P_1V_1}{P_2} \quad \frac{\text{Atmospheric pressure} \times \text{volume Tube 8}}{\text{Final height of mercury column}}$$

and the volume of chamber (V) = $V_2 - V_1$ (volume Tube 8). To check this calibration, the evacuated chamber was connected to the gas burette of an Orsat apparatus. With the delivery tube attached to the gas burette, Stopcock 1 was closed and the inlet stopcock to the gas burette was opened. The volume in the burette, at atmospheric pressure, was recorded. Stopcock 1 was then opened until some convenient reading (P_2) was reached on the mercury manometer whereupon Stopcock 1 was closed. If V_0 equals the volume of gas introduced to the chamber, then the volume of the chamber (V_1) = $V_0 \times$ Atmospheric pressure/P_2.

B. Method of Determination of Gas Evolution: With the apparatus open at Joint 2, the specimen is inserted into Tube 3, which is sealed and evacuated for 30 sec. to approximately 0.1 mm. Hg.; Stopcock 1 is then closed. The entire operation from the beginning of quench to the initial reading can be completed within 90 sec. The volume of gas (at standard conditions) in cc. at any time is equal to $P_1 (V - v) / P_2$ where P_1 = height of mercury manometer, P_2 = atmospheric pressure, V = volume of chamber and v = volume occupied by specimen.

C. Precision of Measurement: The height of the mercury column can be read to ±0.25 mm. which is equivalent to 0.25 $(V - v) / 760$ cc. When the net volume into which the gas is evolving is equal to 160 cc., the gas evolved can be read to ±0.05 cc. (at standard conditions).

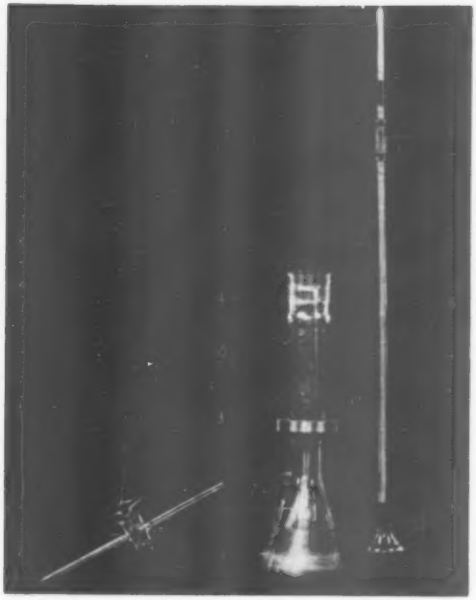

Fig. 2 Insertion of specimen—Method 3

Fig. 3 Method 4 after combustion of evolved gas

D. Possible Errors of Method: Retention of moisture on the specimen or the adsorption of any other gas on the surface of the specimen, which is not removed during evacuation, will give positive errors. The error due to the presence of moisture, which is the most probable, can be eliminated by including a desiccating substance such as anhydrone in the apparatus. Slight tapping on the manometer will avoid errors due to the "sticking" of mercury to the glass.

Method 3

This is an intermediate development (see Fig. 2) in an attempt to combine the vacuum measurement of Method 2 with a cupric oxide–anhydrone analyzing unit. The chief difference between this method and Method 2 is that the evolved gas is concentrated, by means of mercury, into an analyzing unit located at the end of a calibrated tube. As noted in the Introduction, it has been established by many investigators that the evolved gas is predominantly hydrogen. The choice of the analyzing unit was dictated by this fact. The cupric oxide reacts with the evolved hydrogen at about 300° C. to form water vapor; the anhydrone is used to absorb the water vapor.

A. Calibration of Volume of Combustion Chamber: With the combustion tube mounted and inserted, pressure on the gas in the tube was varied by changing the height of the mercury column by tilting the entire apparatus. Pressure of the gas at any time is equal to atmospheric pressure minus the difference in height of the mercury columns. The net volume of the combustion chamber plus the calibrated portion of the tube was calculated by noting the change in total volume with each change in pressure and using the relationship $P_1V_1 = P_2V_2$ (at constant temperature).

B. Method of Determination of Gas Evolution:

(*a*) With Seal 5 open, the specimen is inserted as illustrated in Fig. 2 and the apparatus is then sealed and tilted so that the level of the mercury reservoir is below Tube 2. The apparatus is then evacuated to about 0.1 mm. Hg whereupon Stopcock 8 is closed and the apparatus is righted.

(*b*) To read the volume of gas evolved at any time, the reservoir is opened to atmospheric pressure by opening Stopcock 8. This causes the mercury to rise in Tube 2, engulf the specimen, and enter calibrated Tube 6. The volume of gas evolution is equal to the volume of the calibrated combustion Chamber 7 plus the gas in calibrated Tube 6. Pressure of this gas is equal to atmospheric pressure minus the height of the mercury column above the level of the reservoir.

(*c*) To resume the determination, a vacuum of about 50 mm. Hg is drawn on the mercury

reservoir, thereby eliminating the height of mercury above the reservoir. This allows evolution to take place into the low-pressure chamber.

(*d*) Should a quantitative determination of hydrogen be desired, the gas is collected and read as described in step (*b*) above. Approximately an 8-in. length of 26-gage (B & S) nichrome wire, wound over asbestos, is wrapped around the outside of the combustion chamber and the tube is heated to approximately 310° C. for 15 min. by passing 5 amp. through the nichrome wire. The heater is then removed and the tube allowed to cool. The volume and pressure are again read. The decrease in equivalent volume (volume at standard conditions) represents the amount of hydrogen actually present in the evolved gas.

C. Precision of Measurement: Volumes can be read to ±0.01 cc. with the apparatus described herein.

D. Accuracy of Method: All gases which react with CuO or Cu, with a change in volume, would interfere in the hydrogen determination. CO, which would react with CuO, would not interfere because the CO_2 formed occupies a volume equivalent to that of CO. Oxygen will react with the copper to form oxides. However, the only possible source of oxygen is the atmosphere which contains approximately 80% nitrogen and 20% oxygen. Any error introduced by the entrance of air will be indicated by a low per cent of hydrogen in the final determination and the extent of error can be estimated from the purity of hydrogen recovered. In all determinations conducted with this apparatus, hydrogen was found to be present in concentrations of 95% or higher.

A possible source of error is the entrapment of hydrogen when the mercury engulfs the specimen in step (*b*) above. This may be minimized by allowing the air pressure in the mercury reservoir to build up slowly, and agitating the mercury as it rises in the tube. The combustion chamber components may readily be reactivated. Heating the anhydrone at 250° C. in vacuum for 10 hr. will condition it for additional determinations; the copper will be reoxidized to cupric oxide upon heating in air to 400° C. for 10 min.

E. Materials:

*Part**	*Description*
1	Mercury Reservoir
2	Pyrex Tube—Length to suit, 9 mm. O.D., 7 mm. I.D.
3	Stainless Steel Plate—3 in. O.D., 1/2 in. thick
4	Ground Joint—Standard taper 45/50, outer member
5	Ground Joint—Standard taper 45/50, inner member with reduced tube
6	Pyrex Tube—9 mm. O.D., 7 mm. I.D. Length is such that the beginning of Part 7 is 31 in. above the level of the mercury reservoir.
7	Ground Joint—Standard taper 10/30, complete joint
8	Three-Way Pyrex Stopcock—Bore of plug = 4 mm.
9	500-cc. Filter flask
10	DeKhotinsky cement
11	Scale—0.05 in./division

* Numbers refer to those in Fig. 2.

Method 4

This method (see Fig. 3) combines the simple construction of Method 2 with the analyzing unit of Method 3. Essentially the unit consists of the apparatus of Method 2 adapted to incorporate a cupric oxide–anhydrone analyzer to enable direct hydrogen determinations to be run on the sample of gas collected.

A. Calibration of Apparatus: Identical with that described for Method 2.

To check the analyzing unit, pure hydrogen was admitted in lieu of air. Upon heating the combustion tube, thereby causing the hydrogen to react with the CuO, the volume of residual gas was reduced to zero because the water formed by the reaction was absorbed by the anhydrone desiccant. This was denoted by a zero pressure differential on the mercury manometer.

B. Method of Determination of Gas Evolution: Identical with that described for Method 2.

To determine the per cent hydrogen present, the combustion chamber is heated for 15 min. by passing 5 amp. through the 26 B & S gage nichrome-asbestos heater, and then cooled. The per cent hydrogen present is equal to the change in manometer pressure after heating divided by the original manometer pressure.

C. Precision of Measurement: Identical with that described for Method 2.

D. Materials:

*Part**	*Description*
1	Pyrex Stopcock—Bore of plug = 4 mm.
2	Ground Joint—Standard taper 45/50, inner member with reduced tube
3	Ground Joint—Standard taper 45/50, Outer Member
4	Stainless Steel Base Plate—3 in. O.D., 1/2 in. thick
5	Manometer—Length to suit, 7 mm. O.D., 5 mm. I.D.
6	Scale—0.05 in./division
7	DeKhotinsky cement
8	Tube (supplied with Part 1)
9	Ground Joint—Standard taper 10/30, complete joint

* Numbers refer to those in Fig. 3.

EXPERIMENTAL PROCEDURE

Specimens were saw-cut from various thicknesses of medium steel plate in the as-rolled condition. Table 1

indicates the chemical analysis of this steel. They were then cleaned of dirt and scale by sandblasting. Determinations were made on two brands of an E6015 low-hydrogen type and one brand of an E6010 type of electrode. Welding was accomplished automatically in the horizontal position. Operating conditions are shown in Table 2. Using an automatic "stick-feed" welding head, a bead was deposited with one electrode on one of the steel specimens. The bead was begun on a starting plate, far enough from the edge to permit initiation of the arc and adjustment of the voltage, amperage and rate of travel, before the bead was deposited on the test specimen. It was then carried without interruption onto the specimen, and continued to within about $\frac{1}{2}$ in. of the opposite end. The procedure consisted of depositing single beads, centered on the specimens, under the following conditions:

Length of specimen—5 and 6 in.

Plate thicknesses—$\frac{3}{8}$ in. for $\frac{5}{32}$-in. diameter electrodes; $\frac{3}{8}$ in. or $\frac{1}{2}$ in. for $\frac{3}{16}$-in. diameter electrodes; $\frac{1}{2}$ in. or $\frac{5}{8}$ in. for $\frac{1}{4}$-in. diameter electrodes.

Quench medium—tap water (approx. 60° F.)

Time between completion of welding and quench—15 sec.

Time in quenching medium—15 sec.

Time between completion of quench and beginning of

Table 1—Analyses of Medium Steel Plate

C	0.25
Mn	0.49
P	0.011
S	0.045
Si	0.04
Ni	0.03

Table 2—Results of Tests

Electrode	*Amp.*	*Volts*	*Speed (in./min.)*	*Spec. No.*	*H_2, %*	*Metal deposited, gm.*	*Gas per gram, cc.*	*H_2 per gram, cc.*	*Method No.*
Brand A, Type E6015, $\frac{5}{32}$ in. diam.	130–135	27	4	A21	..	20.7	0.0435	....	1
				A22	..	21.8	0.0412	....	1
				A23	..	21.3	0.0517	....	1
				A24	..	22.1	0.0361	....	1
				A25	88	21.3	0.127	0.112	2
				A26	90	21.0	0.120	0.108	2
				A27	90	21.3	0.114	0.103	2
				A211	..	20.4	0.0441	....	1
				A212	..	19.9	0.0452	....	1
				A213	..	19.9	0.0402	....	1
				A28	..	20.4	0.115	....	3
				A29	93	21.6	0.118	0.110	2
				A210	95	20.4	0.122	0.116	2
Brand A, Type E6015, $\frac{1}{4}$ in. diam.	230–235	30	7	A44	..	33.2	0.0286	....	1
				A45	..	40.6	0.0197	....	1
				A46	..	32.9	0.0213	....	1
				A47	..	32.1	0.0358	....	1
				A41	99	34.3	0.0598	0.0593	3
				A42	99	34.9	0.0894	0.0884	2
				A43	88	33.5	0.0672	0.0592	2
Brand S, Type E6015, $\frac{5}{32}$ in. diam.	130–135	27	4	S21	..	18.2	0.0413	....	1
				S22	..	19.8	0.0378	....	1
				S23	..	17.3	0.0231	....	1
				S24	..	19.6	0.0281	....	1
				S25	97.5	22.1	0.0973	0.0948	3
				S26	88	21.5	0.110	0.0968	2
				S27	92	20.1	0.0975	0.0897	2
Brand S, Type E6015, $\frac{1}{4}$ in. diam.	230–235	30	7	S41	..	32.6	0.0491	....	1
				S42	..	34.9	0.0688	....	1
				S43	..	31.8	0.0661	....	1
				S44	..	24.4	0.0328	....	1
				S45	93	32.6	0.129	0.120	2
				S46	98.4	30.9	0.122	0.120	3
				S47	80	33.5	0.123	0.0984	2
Brand D, Type E6010, $\frac{5}{16}$ in. diam.	150	28	5	D8	..	18.45	0.346	....	4
				D9	..	17.30	0.350	....	4
				D10	..	19.30	0.369	....	4
				D11	..	15.9	0.308	....	1
				D12	..	16.2	0.327	....	1
				D13	..	18.45	0.277	....	1
Brand A, Type E6015, $\frac{1}{4}$ in. diam.	230–235	30	7	A418	..	19.9	0.0956	....	4
				A420	..	32.4	0.0726	....	4
				A421	..	31.8	0.0692	....	3
				A422	..	32.1	0.109	....	4
				A423	..	31.2	0.0898	....	4
Brand A, Type E6015, $\frac{1}{4}$ in. diam.	230–235	30	7	A48	..	31.8	0.0126	....	1
				A49	..	32.3	0.0448	....	1
				A410	..	36.6	0.0109	....	1
				A411	..	35.5	0.0113	....	1
				A412	..	33.8	0.0296	....	1
				A413	..	34.1	0.0293	....	1
				A414	..	32.3	0.0247	....	1
				A415	..	31.0	0.0435	....	1

NOTE: d.-c. reverse polarity was used for all specimens.

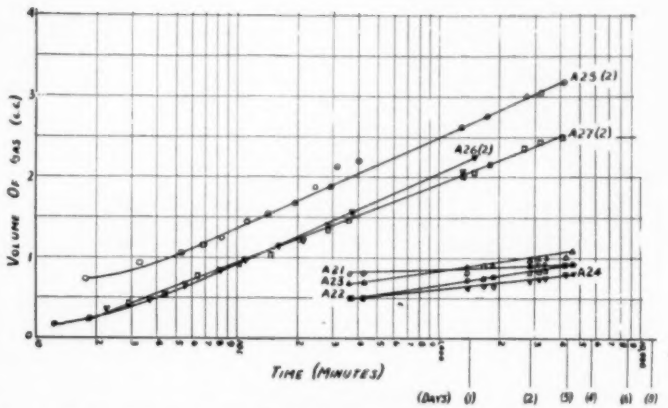

Fig. 4 Rates of gas evolution, Brand A—Type E6015, $^{5}/_{32}$-in. diameter electrode, d.-c. reverse polarity

Numbers on graph are specimen numbers of Table 2. Numbers in parentheses are method numbers. When method is not indicated, the glycerin method (Method 1) was employed

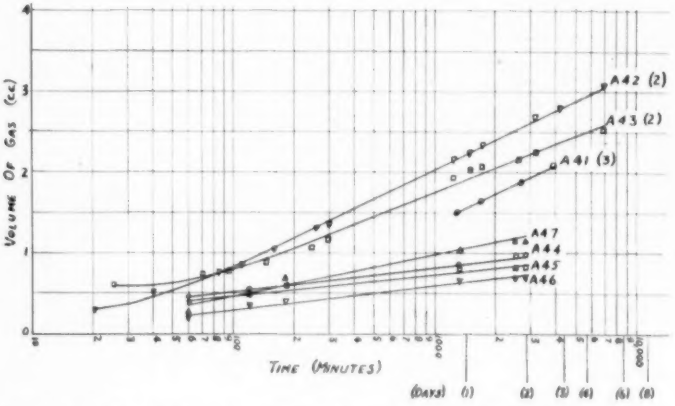

Fig. 5 Rates of gas evolution, Brand A—Type E6015, $^{1}/_{4}$-in. diameter electrode, d.-c. reverse polarity. (See legend under Fig. 4)

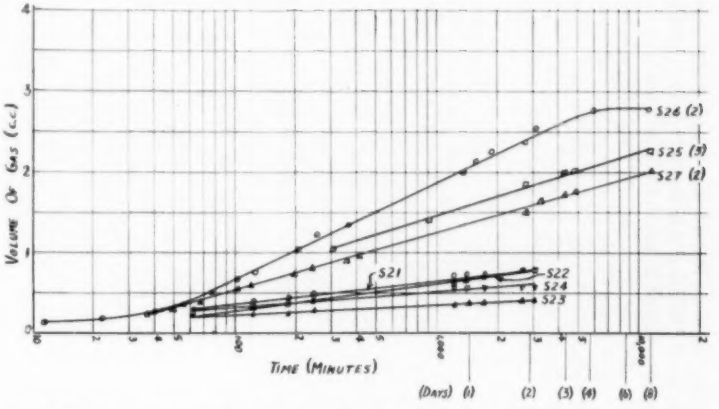

Fig. 6 Rates of gas evolution, Brand S—Type E6015, $^{5}/_{32}$-in. diameter electrode, d.-c. reverse polarity. (See legend under Fig. 4)

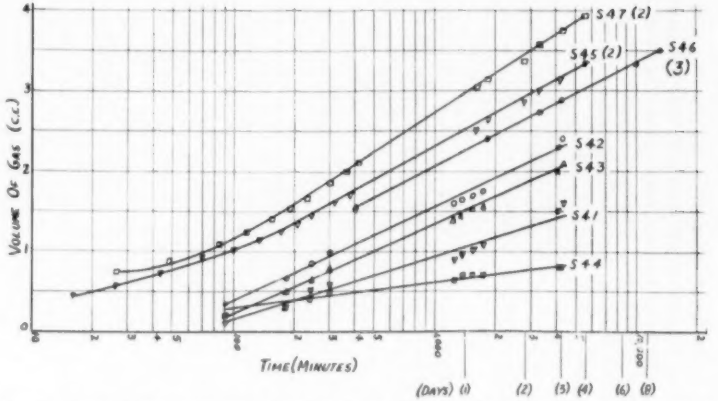

Fig. 7 Rates of gas evolution, Brand S—Type E6015, $^{1}/_{4}$-in. diameter electrode, d.-c. reverse polarity. (See legend under Fig. 4)

measurement—45 sec. for glycerin method (Method 1); 90 sec. for methods 2, 3, and 4.

In addition, analyses were conducted to determine the hydrogen content of the gases collected. For Method 2 a standard Orsat apparatus, utilizing the slow combustion pipette, was employed. For Methods 3 and 4 the hydrogen analyzing unit incorporated in the apparatus was used.

For the first series of tests, several determinations were conducted with each method on each brand and size of electrode, and the rate of gas evolution with time was determined.

To check the possibility that an inaccuracy of the glycerin method may be due to the solubility of hydrogen in glycerin, four consecutive duplicate determinations were conducted at 115° F. with a 2500-cc. crystallizing dish acting as a glycerin reservoir. After the completion of these runs, the glycerin was saturated with hydrogen gas and the determinations were repeated for a fifth time. Before this latter set of determinations was begun, the eudiometer tubes, filled with saturated solutions of hydrogen in glycerin, were kept at 115° F. for 48 hr. to allow excess hydrogen to escape from solution. After the determinations were completed, the temperature of the apparatus, with the eudiometer tubes intact and in place, was raised to 162° F. in an effort to ascertain whether or not additional hydrogen could be released from the glycerin. No additional hydrogen evolution due to changes in solubility was observed.

To check the apparatus and procedure of Method 4, 2.60 to 5.20 cc. of pure hydrogen gas were transferred from a gas burette to the evacuated apparatus. After the change in pressure was indicated by the mercury manometer, the analyzing unit was heated for 15 min. When the apparatus had cooled, a second reading was taken on the manometer tube. Since only pure hydrogen had been admitted to the system, the pressure remaining in the system after combustion was considered as the error in the hydrogen determination. This procedure was repeated 5 times. In each case 100% of the hydrogen was accounted for.

As a further check on this apparatus, four determinations were conducted on specimens of weld deposits, and the purity and quantity of gas collected were compared with those obtained with the other methods.

RESULTS OF TESTS

Table 2 and Figs. 4–8 contain the results obtained by the various methods of determination of volumes of gas evolution together with pertinent data. As indicated therein, approximately 1.5 cc. more of gas is recovered by any of the dry vacuum methods (Methods 2, 3, and 4) than by the glycerin method (Method 1), when analyses are made on weld deposits of "low-hydrogen" type electrodes. This represents an increase of more than 100% in volume of gas recovered. Although a greater total volume of gas also was recovered by the vacuum method in the one set of comparative analyses conducted on type E6010 electrode deposits, a volume differential between methods of the same magnitude (approximately 1.5 cc.) was again detectable.

Figure 9 shows the range of volumes of gas evolved from one batch of low-hydrogen type electrodes during the course of the investigation. This variation in gas evolution was attributed to differences in moisture content of the electrode coatings.

The last set of data of Table 2 shows the results of consecutive determinations conducted using the same batch of glycerin. Figure 10 illustrates the rate of evolution for each determination. As indicated therein, there was a general tendency to collect a greater volume of gas with each subsequent determination conducted with the same batch of glycerin. Curve A49, which exhibits the only major deviation from the general trend, does not follow the pattern of any curve obtained in any determination by the glycerin method. The reason for this deviation is unknown. Efforts to increase the yield by saturating the glycerin with hydrogen before determinations were begun, were unsuccessful.

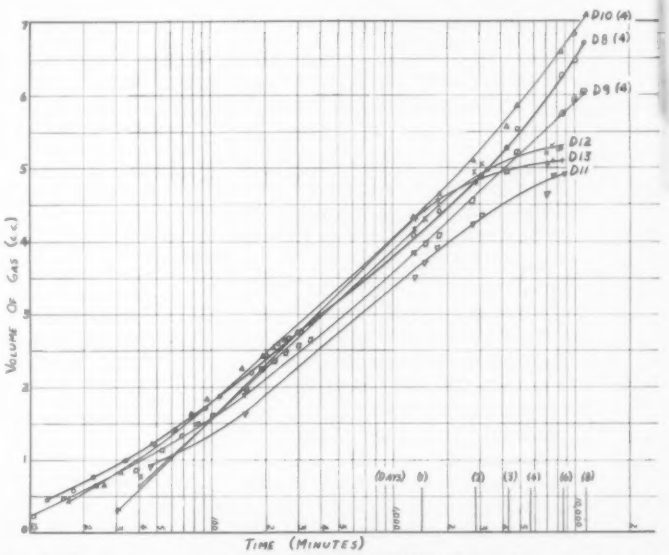

Fig. 8 Rates of gas evolution, Brand D—Type E6010, 5/16-in. diameter electrode, d.-c. reverse polarity. (See legend under Fig. 4)

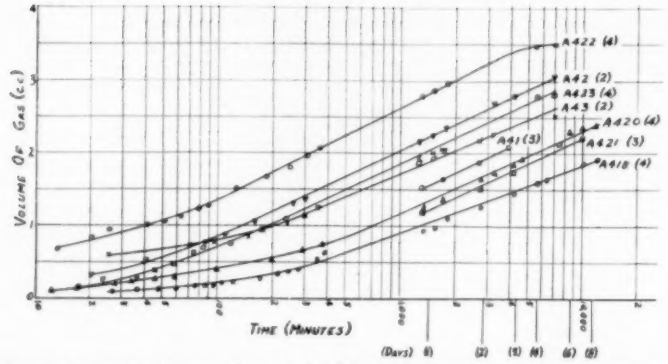

Fig. 9 Range of volumes of gas evolved from one batch of low-hydrogen type electrode, Brand A—Type E6015, 1/4-in. diameter electrode, d.-c. reverse polarity. (See legend under Fig. 4)

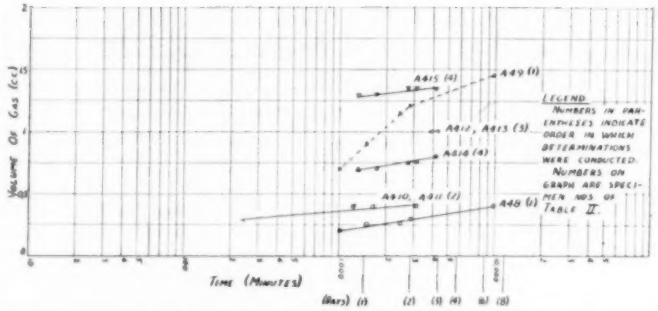

Fig. 10 Consecutive determinations on the same batch of glycerin, Brand A—Type E6015, 1/4-in. diameter electrode, d.-c. reverse polarity

DISCUSSION OF RESULTS

The glycerin method (Method 1) does not appear to be satisfactory for measuring gas evolution rates from weld deposits of low-hydrogen type electrodes for the following reasons:

(*a*) The method does not evidence all the hydrogen available from low-hydrogen type electrodes. The other methods investigated have yielded more than twice the volume of gas indicated by the glycerin method.

(*b*) The formation of gas bubbles on the weld deposit surface prevents an accurate measurement of the rate of gas evolution.

(*c*) The absence of a sharp meniscus, due to scum and foam in the eudiometer tube, detracts from the accuracy of readings.

(*d*) The solubility of hydrogen in a solution of 95% glycerin by weight, as listed in the *Dictionary of Chemical Solubilities* by Comey and Hahn, is 0.0034 Vol. H_2/Vol. liquid at 77° F. The volume of each eudiometer tube is 600 cc. The solubility of hydrogen in this amount of glycerin was calculated to be 2.04 cc. at 77° F. Although data are not available for the solubility of hydrogen in glycerin at 115° F., the temperature at which the determinations in glycerin were conducted, it can be assumed to be slightly less than that noted above. It can readily be appreciated that with the glycerin method, appreciable amounts of hydrogen (between 1 and 2 cc.) would be retained in solution in the eudiometer chamber itself. In addition, there is a loss of hydrogen by means of diffusion out of the open bottom of the eudiometer tube into the main reservoir of glycerin and thus to the atmosphere. This loss cannot be estimated at this time. The principal advantage of the glycerin method is its simplicity.

Method 2 offers a simple means of measurement of volume of gas evolution which eliminates the objections to the glycerin method. The difficulties with Method 2 are the possibilities of positive error due to slight air leakage through the vacuum seals, and the possibility of moisture being retained on the specimen when it is first inserted into the apparatus. Errors due to moisture may be eliminated by including a drying agent such as anhydrone in the vacuum chamber. Errors due to leakage in the system may be detected by a continuous rise in the mercury volumn or by plotting evolution rate against time and noting any deviations from the normal slope of curves of this type. For a 160-cc. net volume of apparatus, readings can be made to ±0.05 cc. of gas (at standard conditions) when a mercury manometer is employed. The sensitivity may be increased over 10 times by substituting oil for mercury in the manometer tube. However, when this is done difficulties are encountered due to diffusion of hydrogen into and through the liquid in the manometer. Accordingly, a mercury manometer was used with this method.

Method 3 represents an intermediate design in which a hydrogen analyzer is incorporated with a McLeod-type vacuum apparatus. In this system, the gas which is evolved into a volume of approximately 180 cc. is collected and compressed in the analyzing unit to a volume of approximately 6 cc. Its chief advantage lies in the fact that with this system gas evolution can be made to take place in a large volume, whereas the

gas is collected and analyzed in a small volume. This permits gas evolution to take place with very low hydrogen pressures in the atmosphere surrounding the specimen. This apparatus may possibly prove desirable in the event that future work indicates that the partial pressure of hydrogen influences the rate and amount of hydrogen gas evolution from the weld deposit. With the apparatus previously described, gas evolution can be read to ±0.01 cc. (at standard conditions).

Method 4 was developed to incorporate the simplicity of design of Method 2 with the analyzing unit of Method 3. In this method, evolved gas passes into and is combusted by the analyzer. The gas is not collected in a small volume prior to combustion as is done in Method 3. The method is accurate to ±0.05 cc. (at standard conditions) and can be made more precise if desired. This can be done by decreasing the net volume of the gas chamber, thereby increasing the pressure rise for a given amount of gas, or by employing a more sensitive means for recording pressures.

CONCLUSIONS

From an examination of the data, it appears that six days is the time necessary for practically all of the hydrogen to be evolved under the test conditions. However, examination of the slopes of each curve indicates that after 100 to 300 min., the evolution rates begin to exhibit a constant slope, for each batch of electrodes. Inasmuch as several points on the straight line portion of the curve are shown, additional gas evolution after 300 min. may be estimated by extrapolation of the straight line portion of the curve to six days. An alternate procedure is to use the equation:

$$y = N + m\ (\log T_2 - \log T_1) \qquad (1)$$

where

y = the total cc. of gas evolved
N = cc. of gas evolved at 300 min.
m = slope of the straight line portion of the curve
T_2 = time when evolution practically ceases (approximately 6 days or 8640 min.)
T_1 = 300 min.

Substituting for $(\log T_2 - \log T_1)$ we obtain the equation:

$$y = N + 1.46\ m \qquad (2)$$

Accordingly, it is possible by either procedure to closely approximate the total hydrogen evolution over a six-day period after only 5 hr. (300 min.) observation.

APPLICATIONS OF THE METHODS

The proposed methods can serve as a basis for improving the procedures in the present electrode specifications for the determination of gas evolution from low-hydrogen electrode deposits. In addition it may prove adaptable for other problems requiring determinations of gas evolution rates. The fact that the apparatus is comparatively inexpensive permits the economical construction of several units, which in turn allows for the conduct of several simultaneous determinations. The designs of apparatus which have been indicated may be modified to suit various sizes and types of specimens. The design may be modified to remove the portion of the chamber containing the specimen from the manometers and seals; the apparatus then may prove suitable for measurements of evolution rates at elevated temperatures by suitably heating the chamber.

ACKNOWLEDGMENTS

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Fatigue Tests of Spot-Welded Steel Sheets

A comprehensive review of a series of fundamental experiments to determine the method of fatigue failure of spot welds in mild-steel and stainless-steel sheets and considerations of possible methods of raised endurance limit of spot welds

by Dr. Georges Welter

1. INTRODUCTION

THE plan of this investigation can be divided into two main parts: first, a description of the fatigue tests under pull-pull loads with steel specimens and secondly, their treatment, mechanical as well as thermal, for improving their endurance limit. A discussion of the results concerning especially the type of fatigue failures obtained with this material in the first period, decided the orientation of the second test period of this investigation. In fact, after the first period, it was necessary to direct gradually this investigation toward more fundamental problems related with these very thin (0.03 and 0.04-in. thick) spot-welded steel sheets. These test series were initiated by a microhardness investigation on the Vickers machine, exploring the welded specimens on their surface, especially in the neighborhood of the spot as well as in transverse and longitudinal sections through the sheet and the spot. This type of hardness test was also used to evaluate roughly the stress and strain distribution in the sheet around the spots. For this purpose, strained and unstrained welded specimens were used and the two-dimensional superficial microhardness results were, for the sake of illustration, represented in three-dimensional diagrams instead of tables. It has also been possible to study the stress distribution around the spot by the appearance of well-discernible Lüder's lines on the surface of the sheet, strained up to the plastic range of the material.

A quite illustrative and interesting test about the main stresses taking place in a tension test, was made by using an artificial spot under fatigue loads. With this test, it was intended to show that the heat-affected zone around the spot is not the main cause of fracture by fissure of the sheet. It could be shown on the contrary that the effect of tension stresses combined with bending stresses, localized around the spot, are the main factors responsible for failure of the thin welded-steel sheets. With an unwelded locally cold-bent sheet, a similar effect could be demonstrated with an artificial spot.

For the determination of stress concentration, leading to failure, and the distribution, as well as the magnitude of the principal stresses around the welds, the brittle lacquer method has been used. Also, strain-gage measurements in the surroundings of the welds, by using gages of an extra small type, in connection with the SR-4 strain-gage indicator, were made to have as complete as possible a survey of the combined tension-bending and compression stresses, taking place in this kind of weld.

Based on these fundamental test results, several quite new and, as it seems, fairly effective amelioration treatments of the spot-welded mild-steel and stainless-steel specimens, could be made and checked by results of pull-pull fatigue tests carried out in a fairly high loading range. Under this point of view, the prevention of repeated bending of the specimens during the fatigue tests seems of basic importance; special means to show the distinctive effect of slight bending, by using a sheath or plate restrainers, were highly effective.

Also an increase of the moment of inertia in the plane of bending, as recognized by the above fundamental strain measurements, should bring some amelioration in the fatigue resistance of these thin spot-welded steel sheets. For this purpose, different types of embossing processes, provided in and near the spot, as well as coining, indenting or compression forces introduced by a local pressing process, should have some positive effect upon the fatigue resistance of these materials.

Furthermore a reinforcement of the

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Table 1—Welding Details

Origin of specimen	*Material*	*Thickness, in.*	*Spot welder*	*Time, cycles*	*Squeeze and hold cycles*	*Pressure, lb.*	*Diameter of spot, in.*	*Remarks*
Aircraft factory, Canada	Mild steel	0.03	Rudel progressive welder, model 130-75H, type N-A		.....	..	1/8	
		0.039			1500 v.	..	1/8	
	1/2 stainless steel	0.03		8	8 condensers	1300	1/8	
	1/4 stainless steel	0.03			.....	..	1/8	
Steel factory, U.S.A.,*	Mild steel	0.03	Taylor-Winfield Rockeram	8	.....	700	3/16	Radius of top electrode, 3 1/2 in.
		0.04		10	30	800	3/16; 7/16	
	Stainless steel	0.03	300 kva.	5	30	800	3/16	
		0.04		6	.....	950	3/16	

* Pullman-Standard Car Manufacturing Co.; Pullman Car Works, Chicago, Ill.

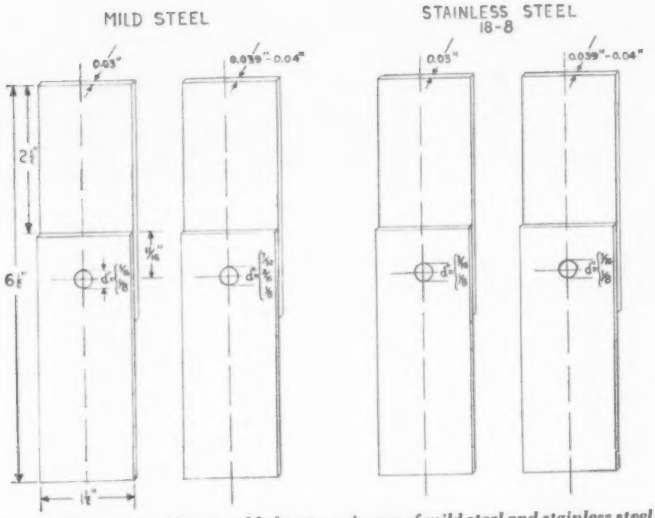


Fig. 1 Dimensions of spot-welded test specimens of mild steel and stainless steel

sheet in the critical zone of fatigue failure around the spot by increasing the metal section of the sheet by compression in closed dies may have some favorable bearing on the fatigue results. The moment of inertia of the spot and the sheet in the plane of bending has also been increased by a displacement of the area of the weld more or less outside the tension plane of the sample. This means that the area of the weld which is under repeated and combined tension-bending stresses, producing the characteristic fatigue failure by fissure of the sheet, is put as far as possible outside of the transmitted forces.

Different types of this kind of improvement have been tried out and several of these seem to indicate that higher resistance against pull-pull fatigue loads in steel specimens can be expected.

2. TEST SPECIMENS

The specimens used for this investigation were partly manufactured in a local aircraft factory in two gages, 0.03- and 0.039-in. mild steel and 18-8 stainless-steel sheets. The over-all dimensions of the single-spot specimens, as shown in Fig. 1, are the same as those described by the author in a previous paper.* The dimensions of the electrodes and particulars about the welding process were for the specimens of different origins as follows: Contrarily to light-alloy specimens (Alclad 24ST) these steel samples were not X-rayed before the fatigue tests, as the consistency of these joints is generally higher than that of light-alloy specimens. The dimensions of the sheets and the spots were chosen in analogy to light-alloy specimens, and their resistance (shear and fatigue) is roughly of the same order as that of light alloy welded sheets despite the smaller gages and dimensions of the spot. Preliminary shear tests with stress-strain diagrams of about every twenty-fifth sample were made to have some indication about the scatter of the breaking load which might also have a bearing on the fatigue results of these steel joints. For the fatigue tests, the specimens were cut to size and provided with two $^3/_8$-in. holes on each side, in order to clamp them solidly in the pulsators. Special jigs were made to drill the holes exactly in a straight line situated in the axis of the spot. Altogether, the following specimens have been received and tested:

Table 2

Material	*Number of specimens* Received	Tested
Mild steel		
0.03 in.	372	241
0.039 in.		
Stainless steel		
0.03 in., $^1/_2$ hard	429	107
0.04 in., $^1/_4$ hard		

3. FATIGUE TESTS ON DIFFERENT TYPES OF PULSATORS

Pull-pull fatigue tests carried out previously with spot-welded light-alloy specimens* showed, after a special hydrostatic amelioration treatment, quite satisfactory results. Based on these results further tests have been carried out with different steel specimens. Especially, mild-steel and stainless-steel samples have been investigated. Thin sheets of only 0.03 to 0.039 in. have been used, having a fairly low fatigue resistance. Contrarily to Alclad 24ST sheets of 0.064 in. thickness, showing, right from the beginning of this type of investigation, different possibilities of improvement of their fatigue resistance, the mild-steel specimens, with a thickness of about half that of the aluminum alloy, behaved under pull-pull loads in a quite distinct way from the thicker aluminum alloy spot welds. A few facts only will be sufficient to illustrate this point which will be discussed later on in more detail:

(*a*) The steel specimens practically never failed during fatigue tests at the interface of the spot while aluminum alloy welds broke fairly often by shearing;

(*b*) Under an identical fatigue load (0 to 500 lb.) as those used for 24ST welds, the sheets of each steel specimen, showing practically no interstice between the sheets before the test, opened up gradually during the repeated loads, having after the test a free space between the sheets of about 0.025 to 0.03 in.; aluminum-alloy specimens of 0.064 in. thickness remained completely straight and were without free space between the sheets after the fatigue test;

(*c*) The thin steel specimens did not maintain the repeated loads in the machine due to local plastic deformation accompanied by slight bending around the spot; welded aluminum-alloy sheets of about double the thickness maintained the repeated loads. The main differences between these two kinds of samples had to be found in their widely different stiffness.

For these fatigue tests, pull-pull loads of 500 to about 780 lb. were chosen. These loads compared to the effective fatigue resistance of these thin gages seem to be fairly high. However, with regard to the small number of pulsators (two only were available during the first half of this year with, respectively, 600 and 1750 cycles per minute) and the extremely great number of single tests which had to be carried out, these higher loads seemed acceptable, despite a certain risk to overlook some amelioration effects of these specimens in the lower loading ranges. It has to be born in mind that the *S-N* curves of treated and untreated specimens may come fairly close together in the range of the smaller number of cycles, while the fatigue limit at 10,000,000 cycles for instance, may be appreciably improved and a much higher load might be applied without failure at the endurance limits, as this is illustrated schematically in Fig. 2. This risk, however, had to be taken in order to investigate the highest possible number of specimens during the time available in this testing period.

The fatigue tests carried out with steel specimens are described according to the material investigated and the different thicknesses, in four main parts, namely:

* "Fatigue Tests of Spot Welds: Improvement of Their Endurance Limit by Hydrostatic Pressure," THE WELDING JOURNAL, 27 (6), Research Suppl., 285-s to 298-s (1948). (Hereafter referred to as Paper 1.)

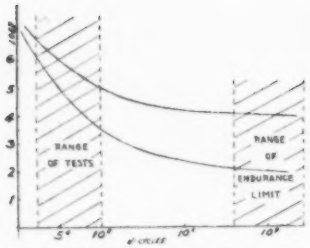


Fig. 2 Scheme of S–N fatigue curves with low and high range of cycles

Fig. 3 Mild-steel specimens with characteristic fatigue cracks near the spot

(*a*) Mild steel of 0.03 and 0.039 in. thickness in the as-received condition.

(*b*) Stainless steel 1/4 and 1/2 hard in the as-received condition.

(*c*) and (*d*) Test results of the same materials as in (*a*) and (*b*) after amelioration treatment.

These tests have been carried out on two pulsators of different type (Frémont Pulsator I, loaded by an eccentric and a lever arm, and Pulsator II, loaded by an eccentric and springs as described in a previous paper*). As these two machines did not furnish the extremely great number of single tests needed, a third pulsator of the twin type, a Krouse fatigue machine, of a maximum capacity of 5000 lb., has been installed in August 1948. This twin machine supplied, in a quarter of a year, nearly as many test results as the two previously mentioned pulsators during about half a year, one of which being a fairly slow machine with about 600 cycles per minute.

3.1 Fatigue Tests of Mild Steel (0.039 in.) in the As-Received Condition and After Mechanical Treatment Under High Pressure

Pulsator I. These tests were carried out on Pulsator I (see paper 1). The failure of these mild-steel specimens took place in all cases on the tension side and in the immediate neighborhood of the spot. The geometrical form of these cracks is characteristic; they represent more or less a sinusoidal curve surrounding the spot in its upper part. Here, the cracks are fairly pronounced and are visible with the naked eye. They are spreading symmetrically on both sides in a downward curved line, becoming gradually of the width of a hair; they finish in a horizontal line right across the sheet and at some distance apart they become untraceable. Depending on the deformation of the specimen and the sensitivity of the electrical device to stop the machine, the length of the crack is generally proportional to the number of cycles recorded. That means that a high number of cycles, until the machine automatically stops, indicates a fairly pronounced length of the crack across the sheet. It is of interest to note that the crack in thin steel sheets takes place always on both sides of the specimen symmetrically and opposite to each other in a zone immediately adjacent to the outside border of the spot. In Fig. 3 are shown some characteristic cracks of this kind in mild-steel sheets of 0.03 and 0.039 in. thickness in about natural size.

It seems important to state that the welded, flat specimens fixed in this machine were guided in the grips so that only a small transverse bending movement of the material around the spot was possible. The grips were so devised as to prevent lateral buckling; this took place especially at the beginning of these fatigue tests, when push-pull stresses were applied on fairly thin sheets. Push-pull stresses were only possible with guided specimens of this kind. The grips of pulsators I and II and the guiding plates B-B' are shown, A and A', in Fig. 4. Later on, when pull-pull tests were made, the same guiding grips were used. The results, with untreated as well as mechanically treated mild-steel specimens to improve their fatigue resistance, as obtained on Pulsator I, are represented in Fig. 5. For the sheet gage of 0.039 in., higher loads were used than for the 0.03-in. thick specimens. Mostly loads of zero to 650 and 780 lb. as indicated on top of each column were applied and the number of cycles necessary, until failure occurred and the pulsator stopped automatically, were recorded. According to this figure, the number of cycles up to failure of two specimens, as received, under a load of 650 to 680 lb., was of the order of 50,000 to 130,000 cycles (black columns, Series I). The specimens represented in the left part of this figure designed by Series I have been welded by a local aircraft factory. For the mechanically treated specimens, hardened compression steel rods of 1/4 in. diameter (see also paper 1), shown schematically in Fig. 6, 6(*A*) and (*B*) were used to produce hydrostatic pressure on both sides of the spot and its adjacent zone. The applied pressure was of the order of 15,000 lb., giving a unit compression stress in the spot area of about 300,000 psi. This fairly high-pressure treatment (load and shape of used steel rod are indicated in each column) produced no special change in the number of cycles of these specimens up to failure. Specimen No. 29, tested under pull-pull loads of 650 lb., showed no important improvement of its resistance; at about 160,000 cycles, failure occurred. A crack appeared in the neighborhood of the spot, as shown in Fig. 3, within and independently of the highly compressed zone. Several other tests of the same type with convex and concave ends of 1/6-in. diameter compression rams (Fig. 6, *b* and *c*) under loads of 15,000 lb. pressure did not bring any remarkable amelioration. The number of cycles of Specimen 14, with a pull-pull load of 710 lb. is not improved; Specimen 21 compressed under 15,000 lb. with convex rams supported a fairly high number of cycles (600,000). Two other specimens were not more resistant than the preceding ones; one was treated with corrugated rods of 1/4 in. diameter under a pressure of 15,000 lb. (No. 16) and the other (No. 18), after having been compressed under 25,000 lb. with a flat rod of 1/8 in. diameter (Fig. 6, *f*, and Fig. 6 (*B*)), was treated by a compression load of 15,000 lb., using a 1/6-in. diameter rod with corrugated ends (Fig. 6, *d*): 100,000 to 230,000 cycles were recorded.

The specimens of this series being exhausted, similar tests were carried out on the same Pulsator I with steel specimens of the same thickness (0.039 in.) but welded at a later date. These specimens were shown to be made, by an error of the

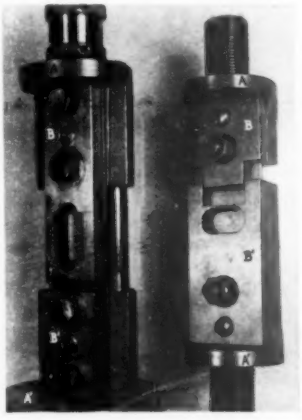


Fig. 4 Grips of pulsators I and II guiding the thin specimens

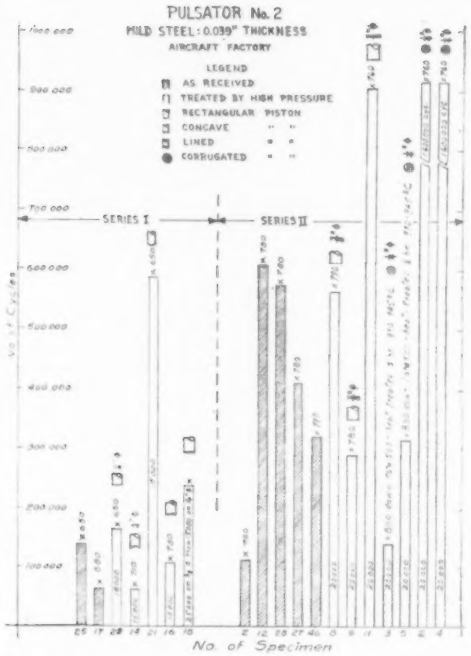
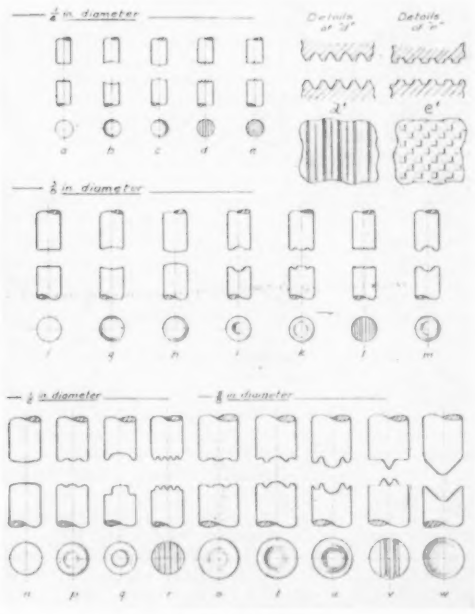


Fig. 5 Fatigue test results on Pulsator I (mild steel 0.039 in. thickness)

factory, of a low-alloy steel (probably CrMo) instead of mild steel (1015). This error was discovered only later on, after a fairly great number of fatigue tests had already been accomplished with this material. From a purely comparative point of view, to find out if hydrostatically treated specimens show a higher number of cycles than untreated ones, it seems that the material itself does not have a special bearing on the results, except for an eventual smaller degree of ductility available in the low-alloy specimens compared to annealed mild-steel samples. The test results with the untreated (black columns) and treated (white columns) specimens of this series are also shown in Fig. 5 (right side). It can be seen that the number of cycles are, in comparison with Series I, distinctly higher for the low-alloy steel specimens (Series II). The untreated specimens had, in the as-received condition, an average of about 300,000 to 400,000 cycles before failure by cracking (minimum 100,000, maximum 600,000 cycles, black columns, Nos. 2, 12, 27, 28 and 46); they were loaded with 710 to 780 lb. Compression treatment under static loads of 20,000 lb., through steel rods of $^3/_8$ in. diameter, with flat compression faces (Fig. 6, *f* and Fig. 5, Nos. 8, 9 and 11, white columns) showed, with the exception of Specimen No. 11, no improvement of the number of cycles which may be of interest; the average of these specimens is about the same as that of untreated specimens. Several other fatigue tests were made with treated specimens, using compression rod faces ($^1/_4$ in. diameter, specimens 3 and 5, Fig. 5) with interlocked grit (Fig. 6, *e*) and heat treatment after compression. This heat treatment consisted in heating the specimen half an hour at about 930° C., followed by cooling in the furnace. The number of cycles was, under a load of 800 lb. at the beginning, less than that for untreated specimens. Two other samples (Nos. 2 and 4, Fig. 5), also compressed with interlocked rams of $^1/_4$ in. diameter under 20,000 lb. (without heat treatment), seemed to be of some-



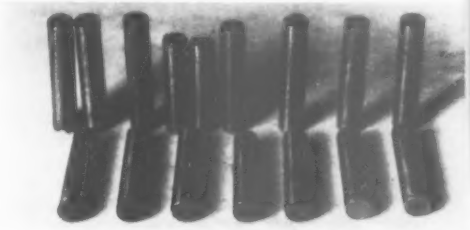


Figure 6 (A)

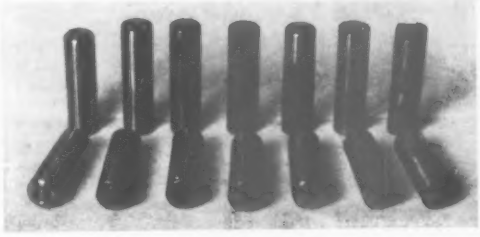


Figure 6 (B)

Figure 6
Fig. 6, 6 (A) and 6 (B) Various forms of compression steel cylinders of $^1/_4$ up to $^5/_8$ in. diameter

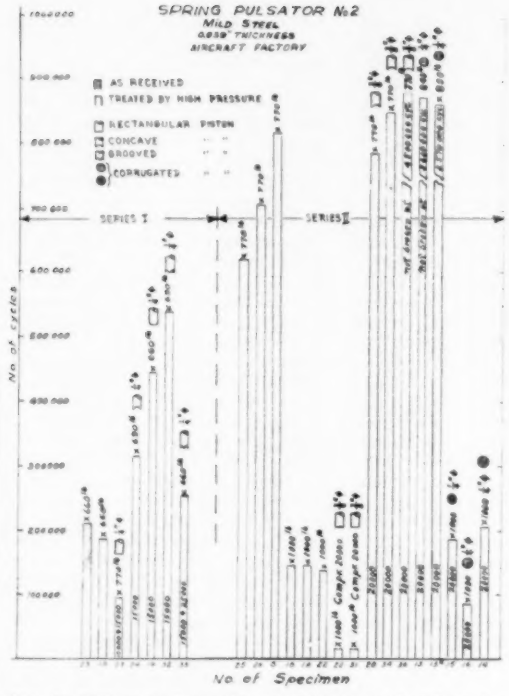


Fig. 7 Fatigue test results on Pulsator II (mild-steel specimens 0.039 in. thickness)

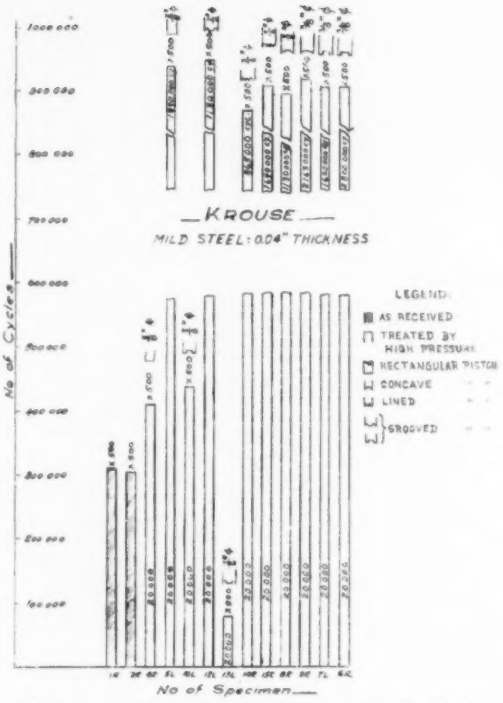


Fig. 9 Fatigue test results on Krouse twin machine (mild-steel specimens 0.04 in. thickness)

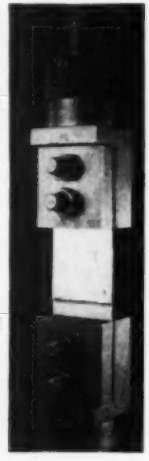


Fig. 8 Grips of Krouse fatigue machine

what superior fatigue resistance; the load of 760 lb. could be repeated over one and a half million times before a crack of the usual shape could be detected in the specimen.

Pulsator II. In order to check the foregoing test results with untreated and treated mild-steel samples of 0.039 in. thickness, parallel tests were carried out on another type of pulsator. This Pulsator II, as described in Paper 1, is based on the deflection of a set of springs under compression, the amount of the load being fixed by an eccentric and a crankshaft. This machine too has been provided with guided grips right from the beginning of the investigation of spot-welded specimens to prevent buckling of the thin welded sheets under push-pull loads; these same grips have been used for the pull-pull fatigue tests with thin mild steel and stainless-steel specimens. Figure 4, right, shows the special grips of this machine guiding the specimen by prolonged cover plates *B-B'*. The free space between the specimen and the cover plate could be adjusted as desired by using spacers of different thicknesses between the cover plate and the specimen. The results of these tests are represented in Fig. 7 in close analogy to the results of Pulsator I, shown in Fig. 5.

Seven specimens, of which five have been mechanically treated and two untreated, showed more or less similar results as those obtained on Pulsator I. The untreated specimens 23 and 13, loaded with 660 lb., supported about 180,000 to 200,000 cycles before breaking in the usual characteristic way. Hydrostatic pressure of 10,000 and 15,000 lb. on a $^1/_4$-in. diameter ram, with square compression faces (Fig. 6, 6*a*, Specimen 27), did not reach the bottom of the spot which is somewhat concave in the as-received condition, due to radius of the top electrode. Under a 770-lb. repeated load this specimen cracked at about 100,000 cycles. Concave and convex ram faces (Fig. 6, *b* and *c*) under a compression of 15,000 lb., improved slightly the fatigue resistance of specimens 19 and 24. Also corrugated rams, according to Fig. 6, *d*, of $^1/_4$ in. diameter, had an equal effect on this material. Specimen 32, after an application of 15,000 lb., showed somewhat over half a million cycles, while an identical treated specimen (No. 33), after applying an additional compression of 25,000 lb., did not show any remarkable improvement.

With specimens of another fabrication series (Series II), made of the same material as that for the preceding tests (low-alloy steel), fairly similar results have been recorded. Untreated specimens 8, 25 and 26, loaded dynamically with 770 lb., had an average of about 600,000 to 800,000 cycles; while loaded from zero to 1000 lb. (specimens 18, 19 and 22), the number of cycles was about 130,000 to 140,000 before cracking occurred. Again by applying a load of 20,000 lb., in compression on a $^3/_8$-in. diameter rectangular ram (Fig. 6, *f* and Fig. 6 (*B*), two speci-

mens under a fatigue load of 1000 lb. (Nos. 22 and 31) showed much lower fatigue resistance (15,000 to 20,000 cycles) than the untreated specimens. On the other hand, concave rams of $^3/_8$ in. diameter, after having applied a load of 20,000 lb. in compression on the spot and its environments (Specimens 28, 34 and 36) revealed somewhat better results, reaching in two instances about 800,000 cycles and in one case (No. 36) more than four and a half million cycles without cracking under a repeated load of 770 lb.

According to the results on Pulsator I, specimens compressed under 20,000 lb. using interlocked pattern of $^1/_8$-in. diameter ram (Fig. 6, *e*), showed again no failure under a load of 840 lb. up to 2,280,000 (Specimen 13). The same specimen, after another test carried out a few days later under a repeated load of about the same amount, failed after an additional 2,570,000 cycles (Specimen 13a). Three more specimens (Nos. 14, 15 and 16), treated under identical conditions with interlocked rams of $^1/_4$ in. diameter, cracked under repeated loads of about 1000 lb. after 80,000 to 200,000 cycles.

Krouse Twin Machine—Fatigue Tests of 0.04-In. Mild-Steel Specimens. As soon as this machine had been received, several check tests with mild-steel specimens of 0.04 in. thickness were carried out. The principle of this machine is well known and need not be described here. The number of cycles are 1750 per minute and the maximum load under which the machine can be operated is 5000 lb. This machine, in comparison to Pulsators I and II, has also been checked dynamically by means of a new circuit, using strain gages, and recording oscillograph. There is no basic difference in the loading diagram of this machine in comparison to the two other pulsators, I and II. Nevertheless,

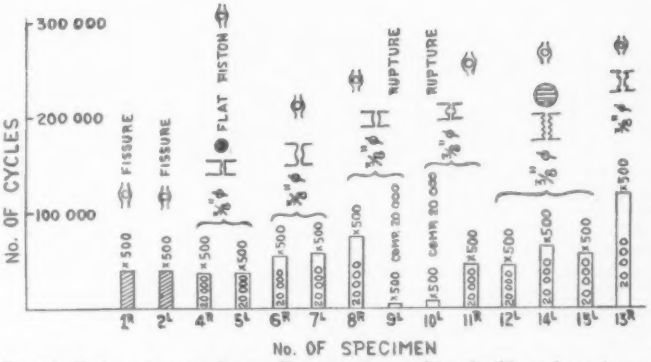


Fig. 11 Fatigue test results on Krouse twin machine (mild-steel specimens 0.03 in. thickness, steel factory, U.S.A.)

the loading grips of the Krouse machine, and this seems for this kind of tests of a certain importance, are of a quite different type. They do not guide the specimen which works during these tests only in tension and not in compression. As shown in Fig. 8 these grips are of a straightforward type; the specimens are clamped by cover plates and bolts in the flat grips on each end and spacer plates of the thickness of the welded sheets bring the specimen in the axis of the loading system. In these grips, the specimen in its overlapped spot-welded part is not guided over a length of about 2 in., contrarily to the grips of Pulsators I and II (Fig. 4,). This means that under loading, each sheet can move freely sidewise and under high-tension loads a kind of slight lateral pulsating movement of the specimen can be observed. This seemingly unimportant fact may, however, account for an appreciably lower number of cycles before failure of the specimen by cracking around the spot occurs. This is due prevailingly to combined tension-bending stresses in both sheets taking place in the immediate neighborhood of the spot. With these remarks in mind, fatigue tests with mild-steel specimens of 0.04 in. thickness, as manufactured in a steel factory, were carried out. The results of these tests are recorded in Fig. 9. By having a look at these results, it can be already observed that the number of cycles of untreated spot-welded sheets, black columns, seems to be lower than those measured on the two other pulsators, I and II. Under a cyclic load of only 500 lb., in comparison with about 650 to 780 lb. on pulsators I and II, only about 300,000 cycles were necessary to produce failure of the specimens by cracking (Nos. 1 and 2). This difference was attributed mainly to the kind of gripping in the two cases, that is, guided and unguided specimens. As it will be shown later, this seems to be of less importance with thicker specimens (0.04 in.) than with specimens of 0.03 in. thickness and less. Compression loads

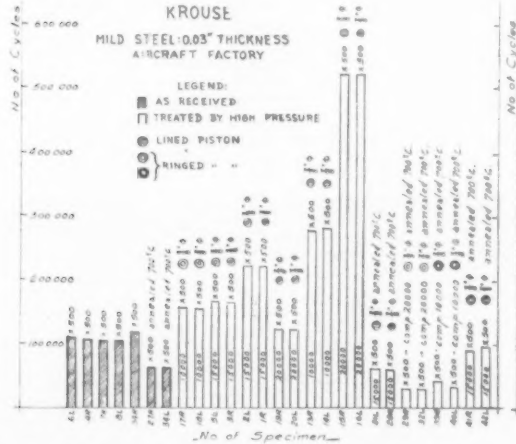


Fig. 10 Fatigue test results on Krouse twin machine (mild-steel specimens 0.03 in. thickness, aircraft factory)

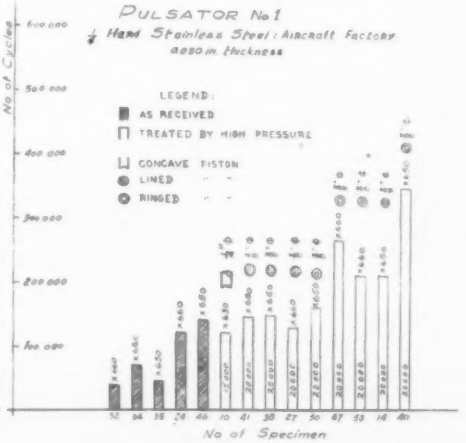


Fig. 12 Fatigue test results on Pulsator I with $^1/_4$ stainless-steel specimens

of 20,000 lb., applied to the spot with a 1/8-in. diameter flat ram (Fig. 6, *f*) seem to bring some improvement of the number of cycles which, under a repeated load of 500 lb., attained 410,000 cycles for Specimen 4R and 1,000,000 cycles for Specimen 5L. Changing the shape of the compression face of the 3/8-in. diameter ram, as shown in Fig. 6, *i* and Fig. 6 (*B*), so that the highest pressure of 20,000 lb. occurred in an outside ring to the welded zone, leaving the weld itself practically uncompressed (10L), brought no special improvement while a somewhat different shape of the ram, compressing the spot and the small outside ring, according to Fig. 6, *k*, brought the number of cycles up to about 1,130,000 (No. 12L); another specimen of this type (No. 13L) failed after only 80,000 cycles. Furthermore, a corrugated ram (3/8 in. diameter), according to Fig. 6 (*l*), compressing with 20,000 lb. specimens 14R and 15R, showed also an increase of 2.5 to 5 times the number of cycles of uncompressed specimens. With concave 3/8-in. diameter rams (Fig. 6, *g*) better results were obtained; for No. 8R, 1,130,000 cycles and for 9R, 2,163,000 cycles, while with concave rams of an analogous shape but with rounded edges (Fig. 6, *m*), the number of cycles could be increased to 1.62 and 2.8 million cycles (Nos. 7L and 6R).

These results with 0.04-in. thick mild-steel specimens, carried out on a quite different pulsator (Krouse machine), as well as specimens of different origin (steel factory, U.S.A.) are in fairly good agreement with those obtained on Pulsators I and II, using specimens welded in a local aircraft factory.

3.2. Mild Steel of 0.03 In. Thickness in the As-Received Condition and After Mechanical Treatment Under High Pressure: Fatigue Tests on the Krouse Machine

In Fig. 10 are represented all fatigue results of the first series of specimens (made by a local aircraft factory) of thin mild steel without and after various mechanical high-pressure treatments. Untreated joints failed by cracking on this machine as can be seen by specimens 6L, 4R, 7R, 8L and 34R, under a repeated load of 500 lb., after a number of about 100,000 to 120,000 cycles. Two especially heat-treated specimens, by annealing at 700° C. (Nos. 27R and 34L), supported a lower number of cycles (60,000) before failure. High-pressure treatment with differently shaped end faces of the rams brought no special amelioration in the number of cycles for these thin specimens. With rams of 3/8 in. diameter, as in Fig. 6, *k*, under loads of 10,000 lb., Specimens 17 and 18 supported 150,000 cycles. Under 15,000 lb. compression loads with the same ram model, the fatigue limit was brought up to 170,000 and 225,000 cycles (Specimens 5L, 3R, 2L and 1R). The same 3/8-in. diameter compression ram, after applying 20,000 lb. on the weld, did not improve the number of cycles under pulsating loads of 500 lb.; both specimens 19R and 20L failed after 125,000 cycles. Another shape of the compression face of the ram, showing a kind of corrugation (Fig. 6, *i*), applying a load of 10,000 and 20,000 lb. on the specimen, had some beneficial effect on the fatigue strength by reaching 275,000 and 520,000 cycles before cracking (Specimens 13R, 14L, 15R, 16L). Further tests with specimens annealed at 700° C. before the mechanical treatment took place, have been tried out to find if eventually a better plastic behavior of the spot under compression stresses improves the number of cycles. By applying the same rams as described before (Fig. 6, *i*, *k*, and *l*), using also similar compression loads, that is, 10,000 to 15,000 lb., these annealed specimens cracked under a much lower number of cycles than the untreated samples tested in the as-received condition. Partly, the cycles were even lower than those of the untreated but annealed specimens 27R, and 34L. This is shown by samples 28R, 29R, 31L, 32L, 40L, 41R, 42L.

Similar tests as the preceding ones were made with a new series of 0.03-in. thick specimens, as-welded in a U.S.A. steel factory. The results of these tests as carried out on the Krouse twin pulsator, are represented in Fig. 11. Under a fatigue load of 500 lb. the untreated specimens seem to be less resistant than those of the preceding series; they show similar values of the number of cycles as the annealed samples 27R and 34L of Fig. 10; all these specimens, treated as well as untreated, supported only an average of about 40,000 to 60,000 cycles with only one exception of 120,000 cycles, No. 13R, Fig. 11. They all failed by cracking except two specimens, 9L and 10L, which failed by shearing, supporting only a few thousand cycles before rupture.

3.3 18–8 Stainless-Steel Specimens Tested on Pulsators I and II—1/4 Hard Stainless-Steel Specimens

In close analogy with mild-steel specimens, 1/4 hard stainless-steel specimens of 0.03 in. thickness were tested on Pulsator I in the as-received and in a mechanically treated condition. The specimens tested in this machine were guided in the grips, contrarily to the fatigue tests carried out on the Krouse twin machine. The fatigue loads applied on these specimens were higher (about 150 to 250 lb. more) than those used for mild steel of the same thickness, because the tensile resistance of spot-welded stainless steel samples under simple tension is, in general, higher than that of mild-steel specimens. In Fig. 12 are shown the results of the first series of 1/4 hard 18–8 stainless-steel samples welded by a local aircraft factory. In the as-received condition, cracks developed under a load of 650 to 660 lb. between 40,000 and 140,000 cycles (Specimens 24, 32, 34, 35, and 46). A mechanical treatment under 15,000 lb. with concave ram of 1/4 in. diameter and different other rams of 3/8 in. diameter of various shapes, according to Fig. 6, *b*, *i*, and *l*), under a load of 20,000 lb., had only a small effect on the test results in so far as a somewhat higher number of cycles was recorded with a maximum of about 350,000 cycles (Specimens 10, 14, 27, 38, 40, 41, 47, 50 and 53). The fissure of the spot of stainless-steel sheets are somewhat different from those of mild-steel specimens, as this is shown in Fig. 13.

On Pulsator II, as shown in Fig. 14, the results with a 1/4 hard stainless steel of 0.03 in. thickness are not much different from those recorded on Pulsator I. As for Pulsator I, the specimens were guided in the grips of this machine. Untreated specimens supported about 10,000 to 50,000 cycles before cracking (Specimens 28, 29, 36, 42 and 43) under a load of 710 to 770 lb., as compared to 650 to 660 lb. used in Pulsator I. A mechanical treatment with 1/4 and 3/8 in. diameter rams of the same shape as those used with specimens tested in Pulsator I, improved somewhat the number of cycles of Specimens 33, 48 and 51. The last two specimens endured about 1,000,000 cycles without failure (Ram, Fig. 6, *m*).

Instead of investigating two different thicknesses, only one thickness (0.03 in.) of this material has been tested and this in two different metallurgical conditions of the material; that is, specimens made

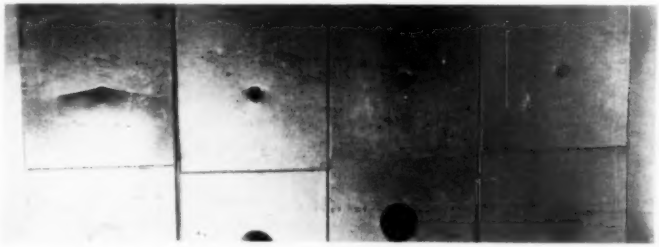


Fig. 13 Quarter hard stainless-steel specimens with characteristic fatigue cracks near spot

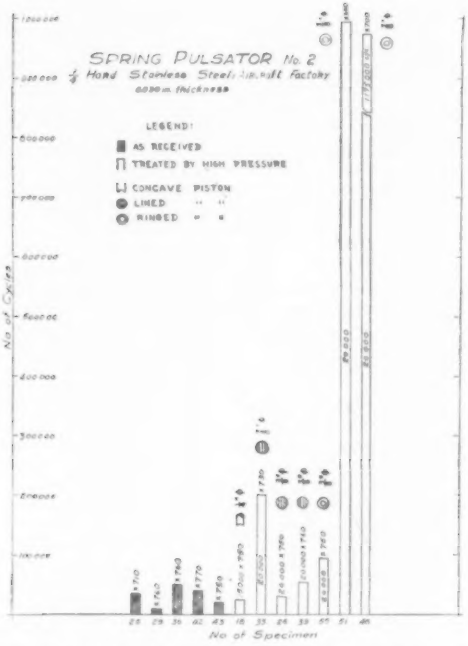


Fig. 14 Fatigue test results with ¼ hard stainless-steel specimens on Pulsator II

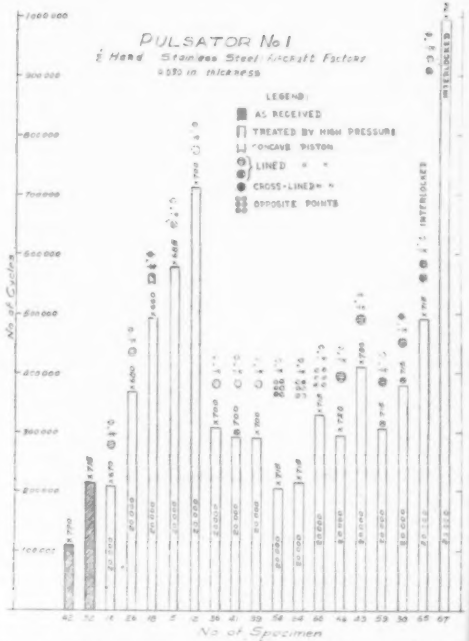


Fig. 15 Fatigue test results with ½ stainless-steel specimens on Pulsator I

of ¼ and ½ hard sheets. These two kinds of specimens were tested for checking purposes on the two described pulsators, I and II, with different loading systems.

Half Hard Stainless-Steel Specimens, Fig. 15 (Pulsator I, Specimens Guided in the Grips). The results of the specimens in a ½ hard condition obtained on Pulsator I were not very much different from those recorded with ¼ hard sheets of the same material and thickness tested in the same machine. Untreated specimens 42 and 52 were lowest with about 100,000 to 200,000 cycles, while all mechanically treated samples, under a pressure of 20,000 lb., applied by ¼-in. diameter rams of different pattern, according to Fig. 6, *b* and *e*, gave better results. Rams with a pattern of parallel line coined in the longitudinal or transverse direction of the applied loads attained 200,000 to 720,000 cycles (Specimens 5, 12, 16, 26, 18, 36, 39 and 41). A ram pattern of small protruding points in a position opposite to each other, according to Fig. 6, *e* and *e'*, remained practically without remarkable influence on the fatigue resistance of Specimens 54, 64 and 66. However, rams with engraved lines placed in a crossed position on the spot and compressed under 20,000 lb. (Specimens 43, 46 and 59) seem to improve somewhat the fatigue resistance of these specimens, being 300,000 to 400,000 cycles. Rams of the same kind but producing an interlocked effect on the sheet and the spot, as shown in Fig. 6, *e'*, gave even still better results. Under fatigue loads of 715 lb. about 500,000 to 950,000 cycles were measured, as shown by Specimens 65 and 67.

Half Hard Stainless Steel on Pulsator II (Specimens Guided in Grips). These test results, as presented in Fig. 16, are in their main lines in accordance with those obtained on Pulsator I. It can be seen that for untreated specimens, the number of cycles up to failure obtained on this machine are more than twice as high as those of Pulsator I. This cannot yet be explained completely, due to the fact that a dynamic calibration of Pulsator I, contrarily to Pulsator II and the Krouse twin machine, could not yet be carried out. Pulsator I is a fairly slow machine with about 600 cycles per minute. At the time the calibration of the pulsators was carried out, this machine was not in action because of fundamental changes in the loading system in order to bring up the number of cycles to about 1200 per minute. The effect of a higher number of cycles of the specimens before failure in Pulsator II in comparison with Pulsator I, has been observed during preceding test series with ¼ hard stainless-steel specimens. This may be attributed to the guided grips which, being of a different type, might be more accurate than those of Pulsator I. This fact, however, does not question the results of Pulsator II as a whole. The main point is that a certain proportion between the cycles of improved specimens compared with untreated ones could be observed. In this respect, the results on Pulsator II are, to a certain extent, comparable to those indicated by Pulsator I.

According to Fig. 16, untreated ¼ hard stainless-steel specimens failed after enduring about 270,000 to 540,000 cycles (Specimens 37 and 57) under dynamic loads of 630 and 770 lb., respectively.

For mechanically treated specimens under a high hydrostatic pressure of 20,000 lb., that is, about 400,000 psi. using a ram of ¼ in. diameter, the number of cycles before rupture could be markedly increased. A compression ram impressing close parallel lines in a circle of ¼ in. diameter (Fig. 6, *d*) on the spot and its close surrounding zone, brought some improvement. The parallel lines, if situated in the axis of the tension stresses applied to the specimen (Specimens 27, 28 and 32) under dynamic loads of 720 and 650 lb., improved slightly the average of the number of cycles before cracking, that is, 400,000 to 450,000 cycles and in one case 1,260,000 cycles were recorded. If these lines are situated in a transverse direction to the loading axis of the specimen, still better results could be found. Specimen 40, treated in this way, withstood 730 lb. about 700,000 times, while Specimens 29 and 31 did not break under loads of 630 lb. repeated 5.6 and 7.5 million times. A similar effect was possible with crossed lines of the ¼-in. ram, that is, the

lines were situated on one side of the spot, parallel, and on the opposite side, transverse to the loading axis. Under 730 lb., Specimen 47 supported about 590,000 cycles, while Specimen 50 withstood 300,000 cycles under a repeated load of 660 lb.; the load was, after that, increased to 750 lb. and the failure occurred only after an additional $2^1/_2$ million cycles. Specimen 61, mechanically treated in the same way, did not fail under a load of 770 lb., after having supported over 5 million cycles. Still another type of compression surface for the $^1/_4$-in. diameter ram, as represented in Fig. 6, *e*, showing inside of the coined circle small squares exactly opposite to each other on both sides of the spot, improved also the fatigue resistance of the $^1/_2$ hard stainless-steel specimen. Sample 62, treated in this way, supported a repeated load of 820 lb. about 675,000 times, while Specimen 51, having coined squares of this kind, did not break after 5.1 million cycles under a dynamic load of 770 lb. The pulsator has been stopped after this period of fatigue stresses; the same specimen, after having been loaded with 840 lb., broke after 393,000 additional cycles in a quite different way from the other untreated specimens. The fatigue crack had spread completely around the spot and only one half of the specimen was detached from the spot by forming a hold in the sheet; the other side was completely unaffected, that means no cracks could be observed under a magnification of 2.5 times.

Furthermore, Specimen 34 was different from the preceding ones, in so far as the small squares coined on the spot were not opposite to each other. They were machined in such a way that the squares of one ram were opposite to the holes of the other ram so that these squares, of which about 30–40 were present in a $^1/_4$-in. diameter ram, were interlocked in a certain degree under a pressure of 20,000 lb. This last specimen has been tested under repeated loads of 820 lb. and supported 2.9 million cycles before failure occurred by cracking.

Further tests with $^1/_4$ and $^1/_2$ hard stainless-steel specimens of 0.03 in. thickness were not carried out on Pulsators I and II, as these first series of specimens, welded by a local aircraft factory, were at that time exhausted.

4. RESULTS OF PRELIMINARY FATIGUE TESTS AND NEW ORIENTATION OF FURTHER RESEARCH WORK

The results of these preliminary fatigue tests were considered as not yet quite satisfactory and especially insufficiently understood, as to the stress-strain distribution in and around the spot, in order to be of particular use to find the possibility for increasing the fatigue resistance of spot welds. Whenever some positive effect could be obtained with welded mild-steel sheets of 0.039 in. thickness and $^1/_2$ hard stainless-steel specimens, after having treated the spots mechanically under a maximum high pressure of 400,000 psi. by coining different patterns in the weld and its adjacent zone, it was nevertheless considered as necessary to make some more basic studies about this subject before more effective treatments could be designed and tried out. There was especially the question of why mostly unsatisfactory results have been obtained with treated thin mild-steel specimens of 0.03 in. thickness. By means of complementary experiments, we have tried to get a more complete understanding of the loading process as well as of the stress distribution in these spot-welded thin specimens. It became clear that the fatigue phenomenon occurring in spot-welded thin sheets is not yet sufficiently understood and that a final explanation cannot yet be given for the very low fatigue loads compared to static loads in shearing.

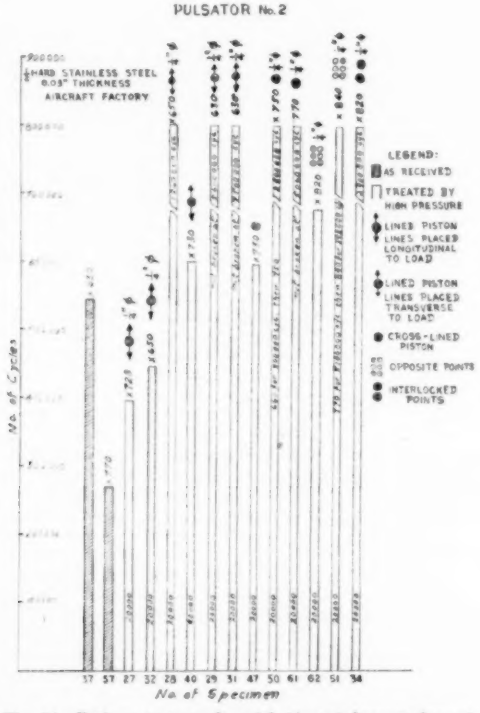


Fig. 16 Fatigue test results with $^1/_2$ stainless-steel specimens on Pulsator II

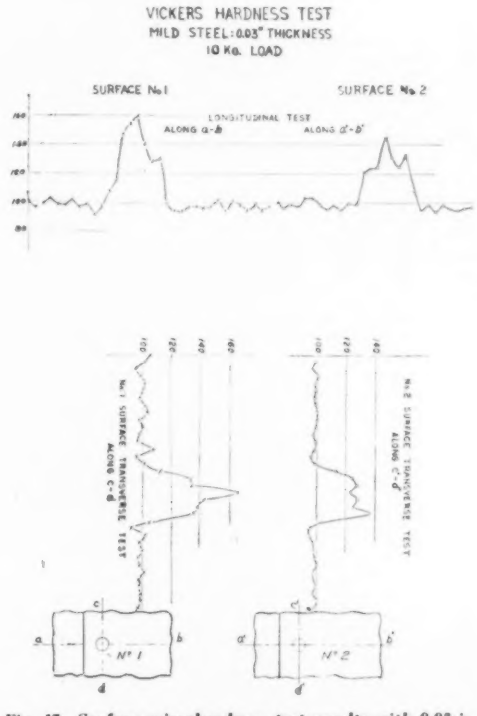


Fig. 17 Surface microhardness test results with 0.03-in. thick mild-steel specimens

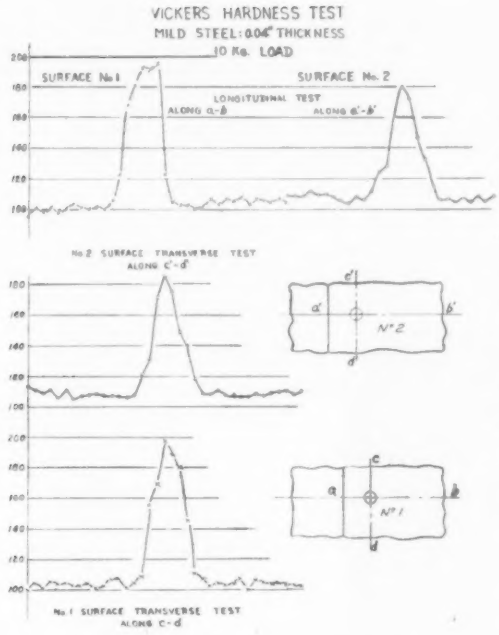


Fig. 18 Surface microhardness test results with 0.04-in. thick mild-steel specimens

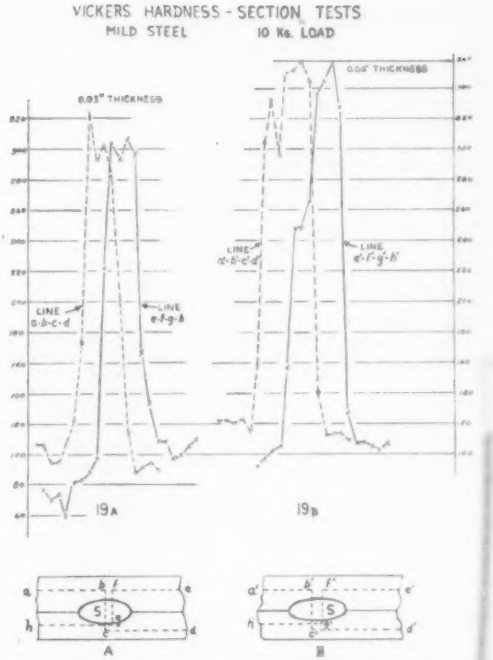


Fig. 19 Transverse section hardness tests on 0.03- and 0.04-in. thick mild-steel specimens

up to rupture. The fatigue phenomenon seems far more complicated than usually admitted. In this phase of the research work, further progress can only be expected after having accomplished a more basic study of this problem. Step by step it has been understood that pull-pull loads do not produce simple tension stresses in and around the spot, but that a far more complicated distribution of various stresses takes place in the welded specimen. Furthermore, there are not only tension stresses which cause the failure of the spot but there are several other stresses active in and especially around the welded joint. Very little thought has been given to bending stresses taking place under pull-pull fatigue loads and nevertheless they seem to be one of the main factors responsible for the low fatigue resistance. Also, compression loads are active in such a weld and the combination of these stresses in tension, compression and bending, together with a very pronounced notching effect, are prevailingly the cause of the fatigue failure under the characteristic small loads. In order to delve somewhat deeper into this complex field of stress distribution and stress combination, a study of several fundamental questions had to be inserted at this point in the course of the research program; they are described in more detail in the following pages.

5. BASIC RESEARCH ON THE STRESS DISTRIBUTION AROUND THE SPOT WELD OF THIN SHEETS

5.1 Hardness Tests

In order to get more fundamental information about the stress distribution around the spot of the sheet, in untreated and treated specimens, microhardness tests were carried out on the Vickers diamond indentation hardness machine. Microhardness tests were made in a longitudinal and transverse direction across the spot on sections through the thin sheets as well as on the surface. With regard to the influence of the load on the diamond indentation in the thin sections of 0.03-in. thick mild steel and $^1/_2$ hard stainless-steel specimens, it was necessary to make some preliminary tests with different loads of which 5 and 10 kg. were chosen. At the beginning, several microhardness test series were carried out with a load of 5 kg.; based on these results, it was found that a load of 10 kg. could be used safely for surface as well as transverse section hardness tests without lateral flow of the mild thin sheet material, giving at the same time a sufficiently clear pyramid indentation for an accurate measurement of the hardness in the surface tests of the sheets. Tests of this kind were run with mechanically treated and untreated mild steel and stainless steel specimens by making surface and transverse indentations. The influence of a certain straining of the welded specimen on the hardness of the spot and its neighboring zone was studied and the longitudinal and transverse surface test results have been represented in three-dimensional diagrams. Also Lüder's lines in relation to strain hardening of the sheets were investigated by these superficial hardness tests.

5.11 Surface Hardness Tests of Treated and Untreated Mild-Steel Specimens of 0.03 and 0.04 In. Thickness

These surface tests were carried out with mild-steel specimens, as-welded in a steel factory. The applied load on the diamond was, for these tests, 10 kg. and in order to check the regularity of the hardness over the surface, the specimens have been investigated on both sides of the welded sheets in longitudinal as well as transverse direction. According to Figs. 17 and 18, the surface hardness has been investigated by making indentations under 10-kg. loads every millimeter, in crossed lines through the spot from one end of the welded sheet to the other, as this is schematically indicated in these figures by schemes 1 and 2. It can be seen by these results that the hardness of thin-mild steel sheets of 0.03 in. thickness did not vary much outside of the spot.

About 92 to 105 V.P.H.N. were measured with most values around 98 to 100 V.P.H.N. in the longitudinal as well as the transverse direction of both surfaces 1 and 2 of the same specimen. As the indentations are a distance of 1 mm. from each other, it can be seen that the spot changes its hardness excessively rapidly from about 100 V.P.H.N. to about 138 to 168 V.P.H.N. in both directions over a length of about 9 mm. This increase of the hardness, of 40 to 60%, takes place over a very small distance on each side of the spot that is over about 4½ mm. from the center. The results on both sides of the sheets are more or less similar to each other; however, it seems that the side under the electrode (Surface 1) shows a somewhat higher hardness of the spot than the opposite Surface 2.

Hardness results of the same type have been obtained with 0.04-in. thick specimens, Fig. 18. The average hardness of these sheets was, outside of the spot, somewhat higher than for the 0.03-in. thick sheet, having 100 to 110 V.P.H.N. The microhardness at the center of the spot was, with 180 to 200 V.P.H.N., also higher than for the thin steel sheets and the hardness variation takes place over a length of about 8 mm. Again, on the side of the electrode, the hardness of the spot is somewhat higher, reaching about 195 to 200 V.P.H.N. compared to 180 to 185 on the opposite side.

5.12 Transverse Section Hardness Tests on 0.03- and 0.04-In. Thick Mild-Steel Specimens

The results of these tests with 0.03-in. thick sheets, using loads of 10 kg., are represented in Fig. 19 (*A*). As indicated in the schemes at the bottom of this figure, representing such a welded section, the microhardness tests were carried out by making diamond indentations at every millimeter through Sheet 1 in the middle of its thickness along the line *a-b* until the center line of the spot *S* is reached. At this point, the indentations are directed in a perpendicular ine *b-c* through the spot until the middle line *c-d* of Sheet 2 is reached. This line is followed making indentations at every millimeter until the hardness does not show any appreciable changes in the sheet. A check test has been made by starting with the indentations at the right side of the top sheet in *e* to *f* going through the spot along *f-g* and finishing the microhardness test at *b* on the left side of Sheet 2. The results of these tests are shown in Fig. 19 (*A*) (left side); Diagram 1 represents the results according to line *a-b-c-d* and Diagram 2 shows the hardness as measured along *e-f-g-h*. In this graph (Fig. 19 (*A*)) it can be seen that the maximum hardness, right in the center of the section of the spot, is appreciably higher than that measured at the surface of the spot in its center (Fig. 17). With 0.03-in. thick mild steel specimens, about 60 to 70% higher values, that is, 300 to 320 V.P.H.N. for the maximum hardness of the spot, have been measured in both cases (lines *a-b-c-d* and *e-f-g-h*). Here, again, the hardness raises very steeply from about 110 V.P.H.N., the hardness of the base metal in the middle of the sheet over a distance of only 2 to 3 mm., up to 300 V.P.H.N. Several of the various transverse test specimens are shown in Fig. 20, after the Vickers hardness tests have been made on the spot-welded sheets clamped together for making the test.

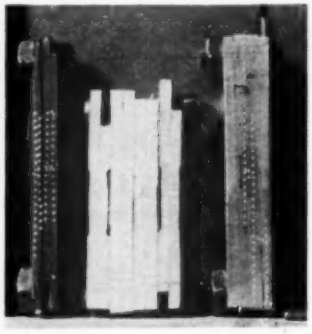


Fig. 20 Several specimens after having been tested in the transverse section on the Vickers hardness machine

The hardness test results with the thicker mild-steel specimens of 0.04 in. thickness (made in a steel factory) are shown in Fig. 19 (*b*). According to the transverse test results, the maximum hardness in the center of the spot of these sheets reaches 360 V.P.H.N. and both hardness results along the lines from the left to the right *a'-b'-c'-d'*, as well as from the right to the left *e'-f'-g'-h'*, through one spot, give fairly conclusive results.

A check test with mild-steel specimens of about the same thickness (0.039 in.), but spot welded in a local aircraft factory, showed surprisingly high-hardness numbers in the transverse section of the sheet as well as in the center of the spot. These microhardness tests, as represented in Fig. 21 (*a*) and (*b*), have been carried out with a load of 10 kg., as represented by the plain line in this diagram and have been checked by a 5-kg. load on the same sheets (Specimens 25 and 43), as represented by the dotted lines. The results of these two different loads of 5 and 10 kg. are in good accordance. These sheets in the as-received condition have a Vickers hardness number of about 150 to 200 units; over a distance of less than 1 mm., an extremely steep hardness increase takes place and reaches with a maximum of 795 units an unexpectedly high value in one spot (Fig. 21 (*a*)) and about 700 units in the other spot (Fig. 21 (*b*)). These results indicated that the material tested could not be mild steel; in fact, tensile tests carried out later on with sheet material of these specimens (0.039 in. thickness) made it clear that these sheets were made of a low-alloy steel (chrome-molybdenum) with quite different mechanical properties from those of mild steel.

The spot welds of two other sheets of this same series, after having been compressed under 20,000 lb. with a ½-in. diameter ram and loaded dynamically without rupture in Pulsator II, for more than 2.2 million cycles (Specimen 41, Fig. 21 (*c*)) by a load of 780 lb., showed no higher hardness than untreated samples. A maximum of about 750 V.P.H.N. has been recorded. A second specimen (No. 37) behaved under the hardness test in an identical manner having a maximum of about 675 V.P.H.N. (Fig. 21 (*d*)). Annealed mild-steel specimens of 0.03 in. thickness showed, after the compression test, an increase of the hardness at the center of the spot of about 25% due to compression under 15,000 lb. by a ram of ⅜ in. diameter; a diagram of this test is not included.

5.13 Transverse Section Hardness Tests with ¼ Hard Stainless-Steel Specimens of 0.03 in. Thickness

These tests were carried out with a 5-kg. load. The results, as shown in Fig. 22, are self-explaining. They show that this ¼ hard stainless steel had a sheet hardness of about 350 V.P.H.N. and the spot, contrarily to mild-steel sheets, is distinctly softer than the sheet having a hardness of only 250 V.P.H.N. (Specimens 32 and 35, Fig. 22 (*a*) and (*b*)). This is, compared to spot-welded mild-steel sheets, completely different in so far as in mild-steel sheets the spot and its environments show much higher hardness than the sheet while the spot in stainless steel sheets is much softer than the sheet itself. This may have a fundamental bearing on the behavior of the fatigue resistance of these spot-welded thin sheets. After having been compressed with 20,000 lb., using a shaped ram of ⅜ in. diameter, the hardness of the spot varied appreciably and an important difference of about 150 to 200 V.P.H.N. between two neighboring points could be observed in this material (Specimens 40 and 47, Fig. 22 (*c*) and (*d*)).

Besides the surface and transverse microhardness tests with steel specimens, about the same number of indentations has been made on treated and untreated Alclad 24ST specimens as well as after fatigue and tension tests. These results will be reported later on when the investigation about light-alloy sheets will be again resumed.

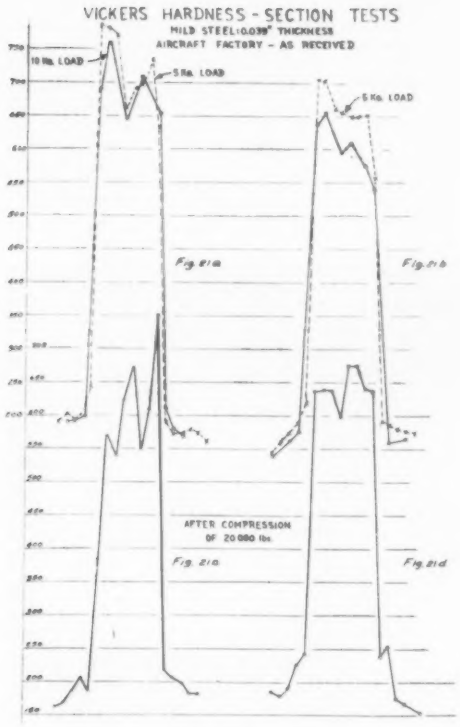


Fig. 21 (Left) Hardness test results in transverse section of 0.039-in. thick sheets

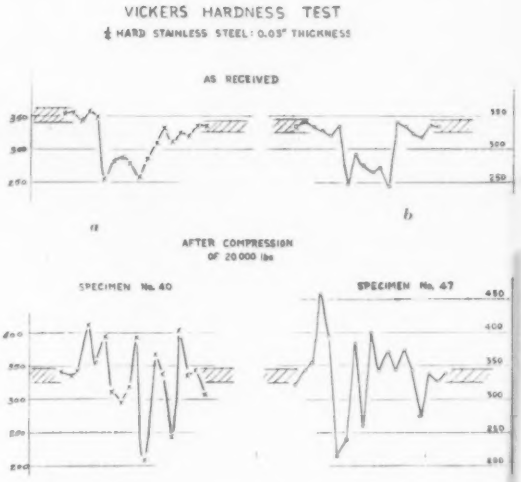


Fig. 22 Hardness test results in transverse section of ¼ hard stainless-steel specimens, 0.03 in. thickness

5.14 Two-Dimensional Hardness Investigation of Strained and Unstrained Specimens of Spot-Welded Mild-Steel Sheets of 0.03 and 0.04 In. Thickness

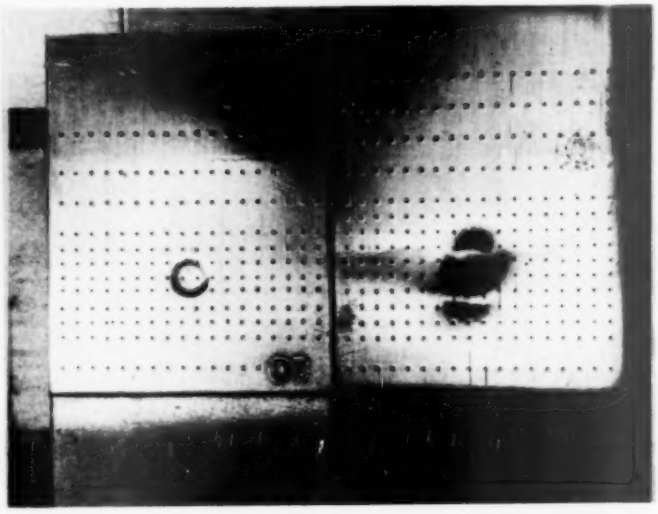
The foregoing microhardness investigation brought us to the idea that a more elaborate two-dimensional survey of the variation of the surface hardness of strained and unstrained specimens could eventually yield some more useful information about the question of the stress distribution around the spot of these thin walled sheets under tension loads. For this purpose, untreated and strained spot-welded mild-steel specimens of 0.03 and 0.04 in. thickness were investigated on the Vickers machine about their superficial microhardness over the whole width and over a length of about 1 to 2 in. on each side of the spot of the specimen. As the pyramid indentations under a load of 10 kg. were made in the transverse direction at a distance of 2 mm. and as these transverse lines were also apart by a minimum of 2 mm. in the most important zones of the welded sheets, the number of the diamond indentations on the surface of each sheet has been fairly great. For each specimen, if tested only on one side, about 150 to 250 single indentations were made and their diameter readings recorded in form of tables. Of these test results, only the most interesting ones are here reported. They represent about 75% of all hardness tests of this type carried out; altogether far over 2000 hardness indentations were made to line up the following three-dimensional diagrams, as represented in Figs. 23 to 32.

The first test of this kind was made with 0.03-in. thick spot-welded mild-steel specimens in the as-received condition in order to have an idea about the hardness distribution in the spot and its environing zones. The specimen has been investigated on both sides of the spot in the longitudinal and transverse directions of the sheets. Figure 23 represents the microhardness results as measured over the surface of 0.03 in. thick sheets. As this could be expected, the hardness does not vary appreciably over the length and width of the sheet (90 to 97 V.P.H.N.) until the border zone of the spot is reached (Fig. 23). Even as near as 1 mm. outside of the spot (transverse lines *4* and *8*) no special hardness increase has been recorded. In the spot itself, however, the hardness rises rapidly from the border line to the interior of the spot (transverse lines *5*, *6*, and *7*) and reaches a maximum of about 128 V.P.H.N. in the center of the spot. Figure 23 (*a*) represents all hardness numbers higher than 100 V.P.H.N., thus indicating zones of special interest. Hardness tests were also made on the opposite side of this spot-welded sheet. The results are similar to those of Fig. 23. Figure 24 (*A*) and (*B*) represents a photograph of these specimens showing micro indentations on their surface after the hardness test (24 (*A*) as-received, 24 (*B*) after tension).

In comparison with these results, there were made tension tests up to permanent deformation on spot welds in the as-received condition of 0.03 in. thickness; these results are represented in Figs. 25 and 26. It can be seen by these results that, due to tension stresses (load 1200 lb.), the sheet yielded around the spot in a fairly small area, producing combined stresses of tension and bending. The zone of plastic deformation of this 0.03-in. thick sheet (Fig. 25 (*a*)) is fairly small as this is also visible by the formation of Lüder's lines around the spot. This effect could be checked by the microhardness curves showing on both sides of the spot and over a small width a distinctive increase of the hardness by plastic flow. The hardness of the spot itself remains about the same, but on both sides, right in the length axis of the spot, there are smaller zones of hardness increase as this is shown by transverse lines *3*, *5* and *6*. After the tension test Lüder's lines are

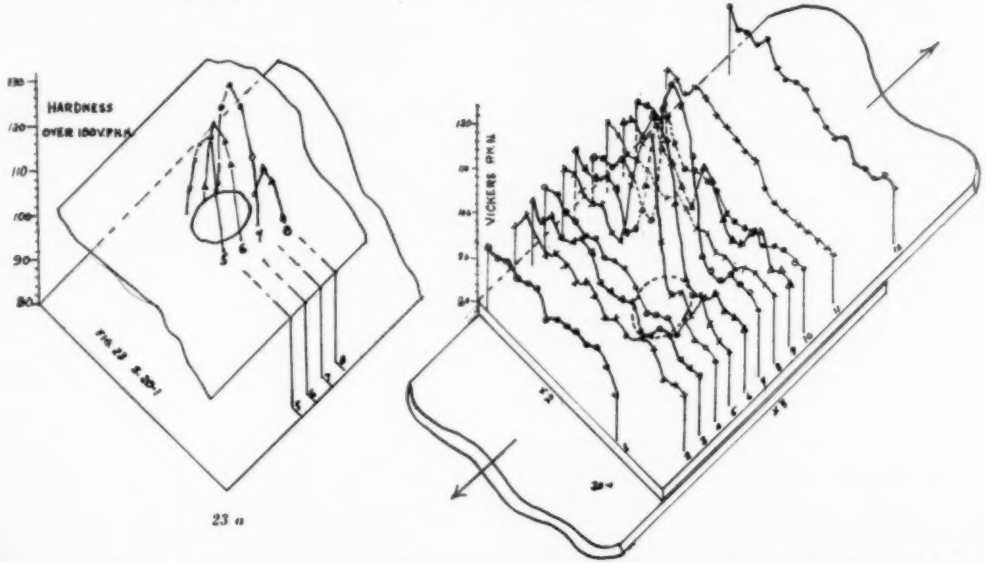
visible in the sheet around the spot. The maximum hardness recorded in the center of the spot is 136 V.P.H.N. Furthermore, the deformation volume of the sheet, as indicated by higher hardness numbers and a pattern of the Luder's lines, is visible in Fig. 25 (*a*) and Photo 25 (*B*). The microhardness results of the annealed 0.04-in. thick welded sheet after having been stretched under a maximum load of 900 lb., are represented in Fig. 26 and 26 (*a*).

In order to have some numerical evaluation of the hardness increase, as measured in these sheets in the zone of plastic flow in the area of Lüder's lines, a sheet of 0.03 in. thickness has been provided with a $^3/_8$-in. diameter hole in the axis of the sheet and submitted to a tensile load. The microhardness distribution over the surface of this sheet is shown in Fig. 27 and 27 (*a*). Lüder's lines on the sheet spreading diagonally under about 45° at both sides of the hole, are visible on the photograph, Fig. 28, taken after the tensile test. This sheet has been stretched under a load of 1200 lb. up to the yielding of the material which took place especially around the hole. The microhardness increase on both sides of the hole as visible in Fig. 27 and 27 (*a*) reached in the yielding zone of the Lüder's lines about 110 to 115 V.P.H.N. compared to only about 93 to 99 V.P.H.N. in the unyielded sheet. This means that the microhardness survey of the surface of a stretched sheet can give some useful information about the zones that yielded under tension stresses. This method has been used to study the local plastic flow of the sheet material around the spot under different loading conditions. Referring to Fig. 25, it can be seen that outside of the spot the yielding of the sheet has taken place about 5 to 6 mm. above the spot reaching in the center zone about 110 to 115 V.P.H.N.; this corresponds fairly well with the microhardness in the yielded material. Furthermore, the unsteady character of microhardness of transverse line 7 of this Fig. 25 and 25 (*b*) indicates, as this could also be seen by the distribution of the Lüder's lines in the sheet, that the hardness of 110 and 120 V.P.H.N. has been recorded in the flow lines themselves while the lower hardness numbers indicate the places between the Lüder's flow lines where no plastic flow of the material has taken place. Furthermore, the zone of plastic deformation of the annealed sheets of 0.04 in. thickness Fig. 26 and 26 (*a*), compared to Fig. 25, is fairly small. There seems especially to be a bending effect taking place in the sheet around a horizontal axis through the center of the spot. Due to this bending effect, the



A *B*

Fig. 24 Mild-steel specimens after the test



23 a

Fig. 23 Mild Steel Specimen as received 0.03 in. thickness; in fig. 23(a) Hardness numbers higher than 100 V. P. H. N.

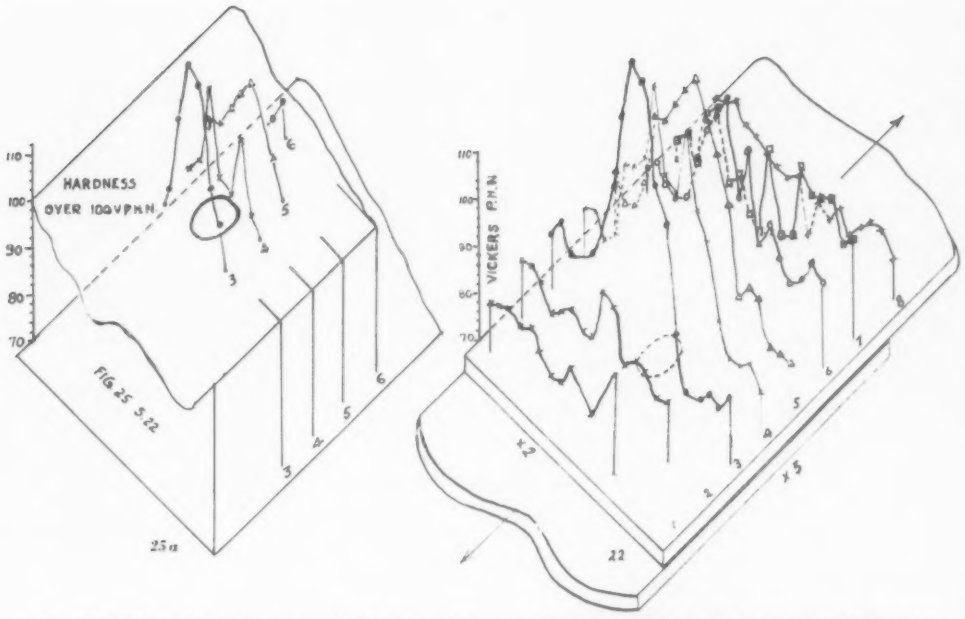


Fig. 25 Mild steel specimen as received 0.03 in. thickness. After plastic deformation without guiding device

zone of plastic flow is appreciably reduced contrarily to specimens in the as-received condition Fig. 25 and 25 (*a*).

By this simple test, it could be learned that the bending effect taking place under simple tension seems of fundamental importance concerning the behavior of spot welds of thin sheets under fatigue loads. Furthermore, from these tension tests combined with microhardness investigation the following basic statement could be made. The resistance of this kind of welds, that is tensile and probably fatigue as well, may be improved if the zone of plastic deformation around the spot can be increased in the sheet. It can be expected that this might be possible by preventing the welded sheet to bend in its horizontal transverse axis through the spot. To confirm this assumption the first step to be taken was to place a simple steel sheath around the spot guiding both sheets. Already the first tentative test carried out in this direction was successful, in so far as the limit of proportionality between stresses and deformations could be increased by these means by about 40 to 50%. This is shown in Fig. 29, representing load-deformation diagrams of welded thin steel sheets (0.03 in.) with and without guidage of the sheet. Without guidage, the proportional load of these welded sheets is about 720 lb. and a maximum load of 890 lb. has been attained; the same type of specimen tested with a sheath has a proportional limit which is about 40 to 50% higher and shows a maximum load which also is about 50% higher than that of the unguided joint. Furthermore, it can be seen that the total energy absorbed by the guided weld is at least 3 to 4 times that of the unprotected weld (compare surface S and S' covered by the load-deformation diagram). Furthermore, the guided specimen remains completely straight after the tension test compared to the unguided specimen which opens up by lateral bending. The spot itself turns out of the central axis of the load by a certain angle which depends on the applied maximum load. For tests carried out with 0.04-in. thick specimens, this striking difference was somewhat smaller (about 30 to 35% for the proportional limit and the maximum load) as these thicker sheets are by nature somewhat more rigid.

With the test specimen loaded up to plastic deformation in the sheath, hardness tests over the whole surface surrounding the spot, were carried out. These microhardness tests gave some interesting results about this kind of axial loading, as represented in Figs. 30, 31 and 32, showing hardness results of guided specimens of 0.03 and 0.04 in. thickness. Only a part of the surface-hardness tests of this kind, made with guided specimens have been reproduced. It can be seen by these figures that the zone of plastic flow, represented by increased microhardness, is much greater than that of unguided welds (Figs. 23 and 25). These zones of increased microhardness can easily be reproduced as shown in Figs. 30 (*a*), 31 (*a*) and 32 (*a*), according to the hardness survey of the surface of the plastically deformed sheets. These results are also in good accordance with the pattern of the

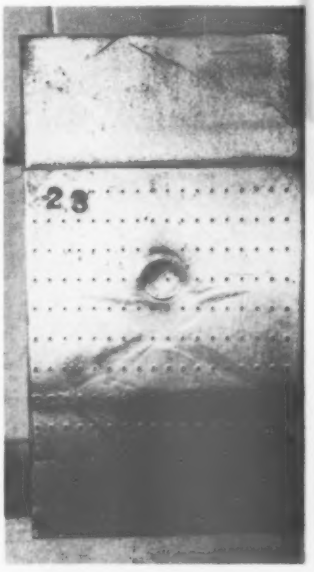


Fig. 25B

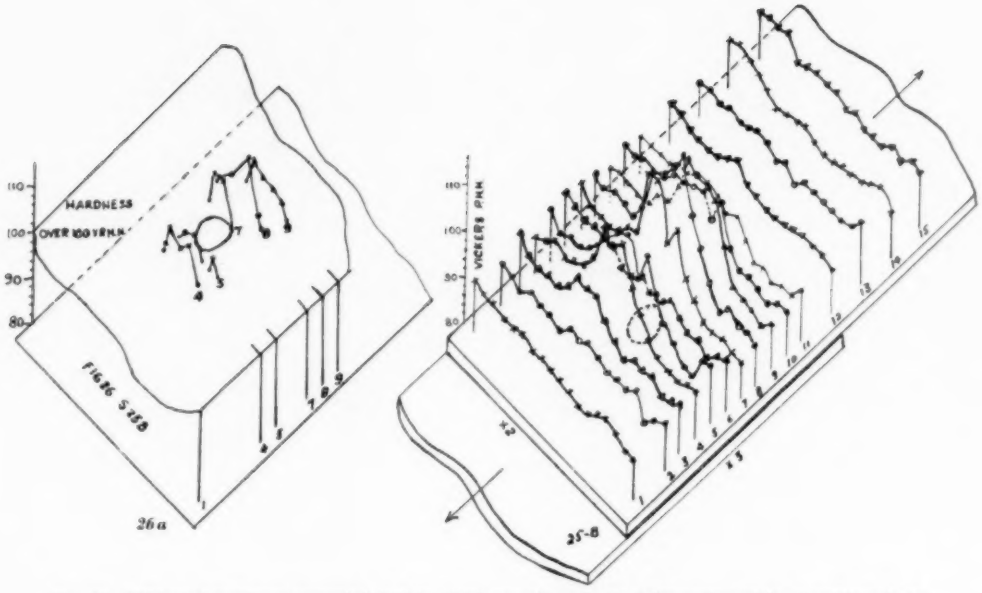


Fig. 26 Mild steel specimen annealed, 0.04 in. thickness after plastic deformation without guiding device

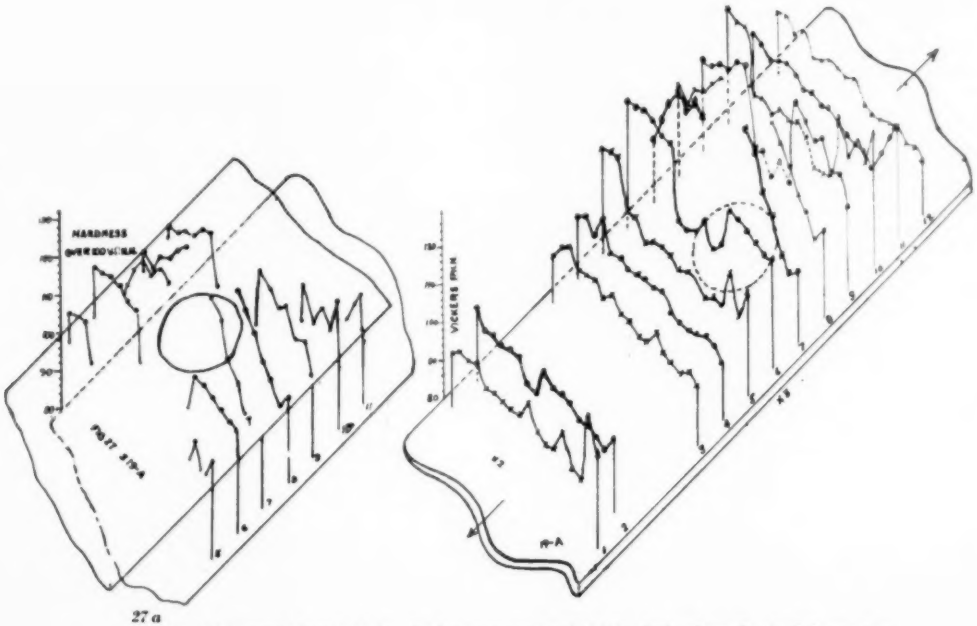


Fig. 27 Mild steel sheet 0.03 in. thickness as received—$^3/_8$ in. hole after plastic deformation

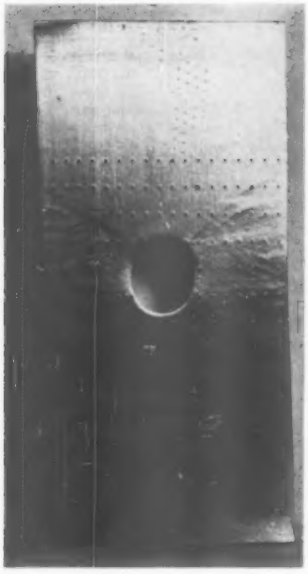


Fig. 28 Lüder's lines in a stretched mild-steel specimen

Lüder's lines visible on the surface of the polished sheets after the test, as this is shown in Fig. 33 (*a*). These zones are more or less in a certain relation with unguided stressed specimens, as this is shown in Fig. 33 (*b* right). Guided specimens have a deformation zone which is at least 100 to 200% greater than the unguided specimens having a kind of two small half-moon zones around the spot while guided specimens show a quite characteristic pattern of Lüder's lines spread under an angle of about 45° over the surface across the whole width of the sheet.

5.2 Artificial Spot Under Fatigue Stresses

The above test results brought us to the conclusion that there are prevailingly combined stresses in operation around the spot which cause the characteristic fatigue cracks under repeated loads, according to Figs. 3 and 13. The assumption of a low-resistant heat-affected zone around the spot as source of its small fatigue resistance seemed to be, under the light of the foregoing results, not very acceptable. These test results indicated that the fatigue cracks are mainly due to tension stresses combined with bending stresses which are in action around the spot and which togetner with a certain effect of notching account mainly for the astonishingly low number of cycles before failure occurs in the welded steel sheets near the spot.

In order to gain some more material supporting this point of view, a special

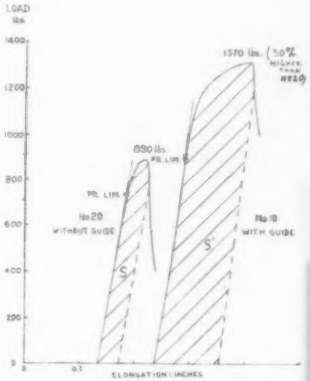


Fig. 29 Load deformation diagrams of welded thin (0.03 in.) sheets with (right) and without (left) guidage of the sheet

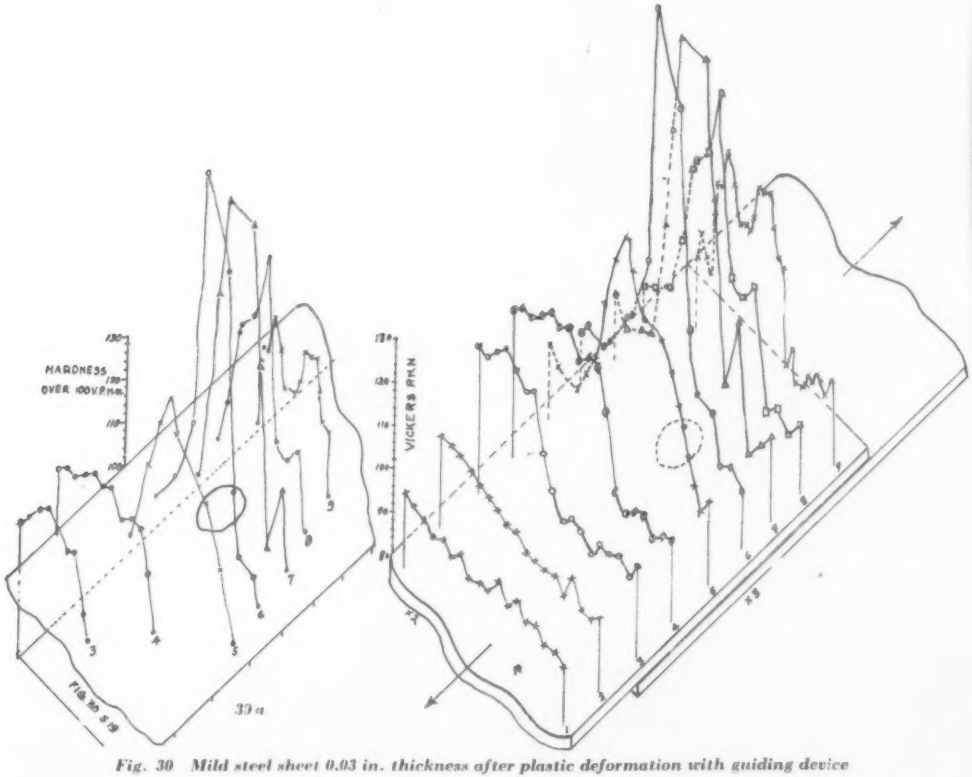


Fig. 30 Mild steel sheet 0.03 in. thickness after plastic deformation with guiding device

test with an unwelded specimen, provided with an artificial spot, has been made. This artificial spot has the same diameter as the spots of the resistance welded sheets tested during this investigation. Two mild-steel sheets of 0.03 in. thickness were fixed together without heating the specimen up to the melting point of the material. Without application of any

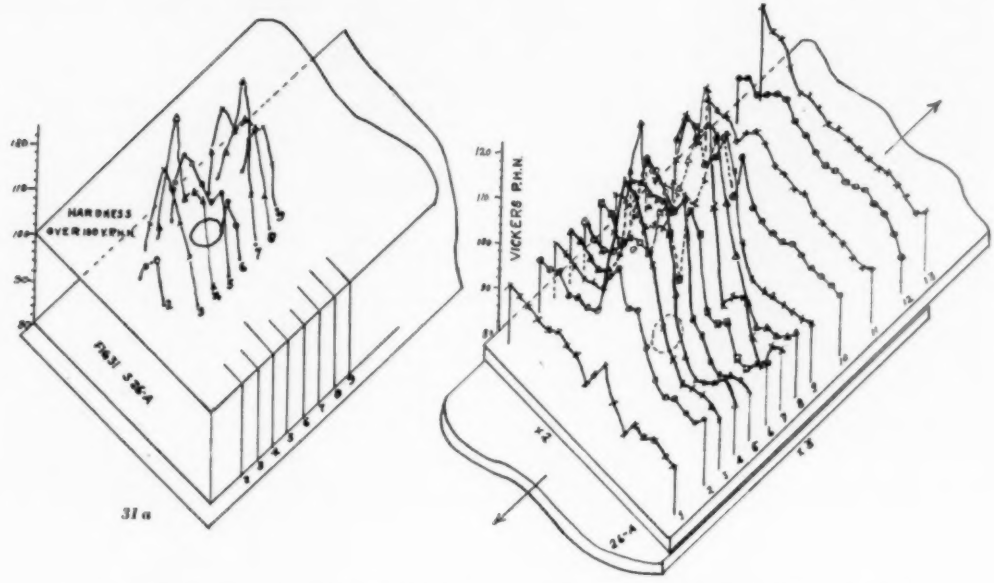


Fig. 31 Mild steel specimen 0.04 in. thickness annealed after plastic deformation with guiding device

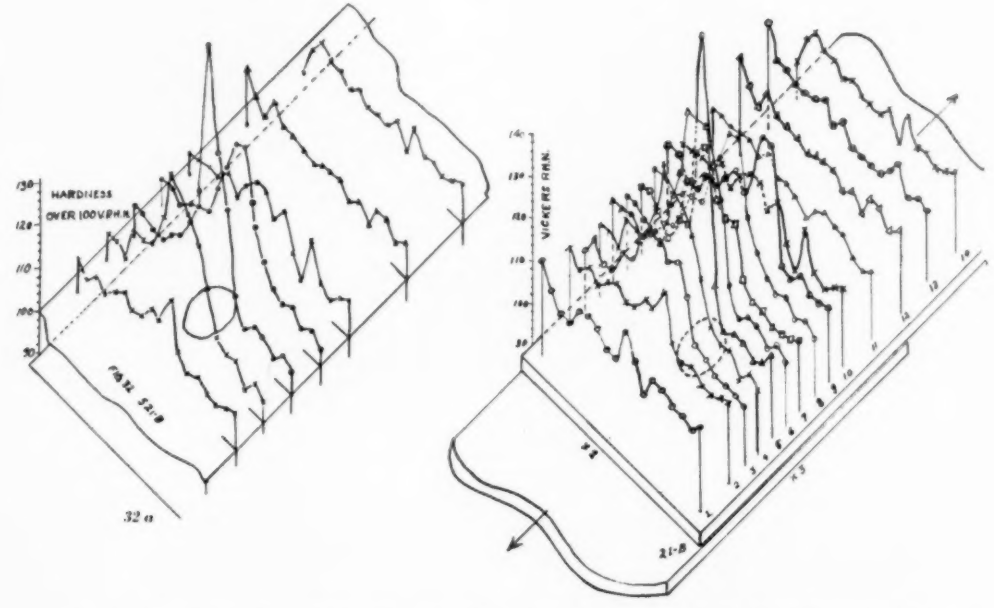
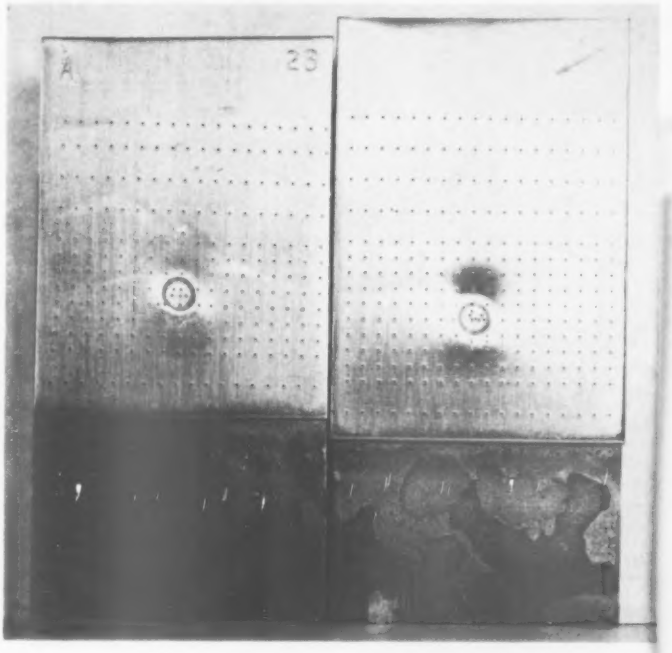


Fig. 32 Mild steel specimen 0.04 in. thickness after plastic deformation with guiding device (as received)

heat at all they were mechanically clamped together by short hardened-steel cylinders of the same diameter as the spot. As shown in Fig. 34, these cylinders a-a' were pressed against the overlapped sheets b-b', with two small transverse bars c-c' and two screws d-d', over an area equal to the bounded surface of the spots used in this investigation. Between the transverse bars c-c' and the cylinders a-a' was placed a half-round bar, having a smaller radius than that of the cylinder on which it transmits the load. This has been provided in order to permit the two cylinders to follow the small bending movement of the sheet under repeated tension. Furthermore, in order to increase the adhesion of the sheets in the circular zones of contact under the short cylinders, they were roughened by a kind of light surface corrugation having a somewhat smaller diameter than the steel cylinders pressing the sheets together. With two steel screws d-d' of $^3/_{16}$ in. diameter, a sufficient pressure could be developed between the sheets so that it was possible to raise the applied loads up to the fatigue loads used for the welded specimens tested under repeated loads. These artificially clamped specimens behaved in the fatigue machine in an identical manner as the ordinary spot-welded specimens. This is especially true regarding the number of cycles before failure which is for the artificial spot about the same as for the spot-welded sheets. Furthermore, the failure took place in exactly the same characteristic manner as in the case of spot-welded sheets, that is, by cracking of the sheet outside and around the small cylinder clamped on the specimen. Under a repeated load of 500 lb. the number of cycles of a 0.03-in. thick sheet was in one test 72,600 and in another one 73,400 before failure of the sample. This represents a fairly good average of the number of cycles for spot-welded samples of the same size as tested in the Krouse fatigue machine. The most interesting fact, however, is that the failure by cracking of the sheet is not at all different from that of spot-welded sheets, having by nature of the welding process a heat-affected zone around the spot. This zone is generally regarded as the weakest part of the joint. Figure 35 represents a photograph of the cracks of several sheets tested in this way with an artificial spot. These tests prove that the fatigue resistance of the sheet with an artificial spot (without any heat-affected zone) is identical and as low as that of material spot welded under high temperatures. From these tests, the important fact can be deducted that the spot-welded sheet is not weakened in its fatigue resistance by the so-called heat-affected zone around the spot. Its low fatigue resistance is more likely a direct effect of the combination of tension and bending stresses rising to a fairly high amount exactly in the zone adjacent to the spot joint, as this could be shown by this experiment with artificial spots.

5.3 Combined Tension and Bending Fatigue Tests as Taking Place in the Adjacent Zone of the Spot

In order to get some more convincing material along this line of tests, showing the harmful influence of combined tension and bending stresses on the fatigue resistance of mild steel, tests with unwelded single sheets, designed so that combined stresses take place under repeated tension loading, were carried out. For this purpose, 0.03-in. thick sheets were bent in their central part in two transverse lines in such a way that a certain eccentricity



(*a*) (*b*)

Fig. 33 Guided (a) and unguided (b) specimens after the hardness tests

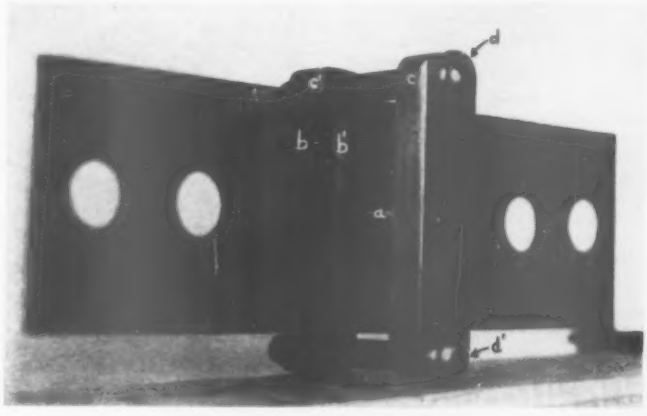


Fig. 34 Specimen with artificial spot

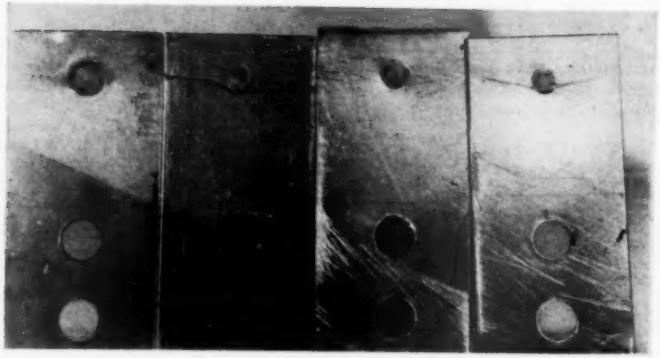


Fig. 35 Fatigue cracks of artificially joined specimens

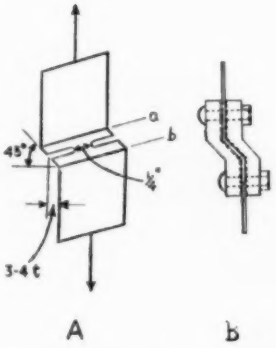


Fig. 36 Specimens for combined tension and bending fatigue tests

of the tension loads has been attained. As shown in Fig. 36 (*A*), the specimen of 1 1/2 in. width was bent in two places *a* and *b* by an angle of about 45° over a length of 1/4 in., so that an eccentricity of about 3 to 4 times the sheet thickness was obtained. In order to support the fatigue load of 500 lb. in the bent part of the sheet a kind of short guiding sheath has been provided on the central part of the specimen as illustrated in Fig. 36 (*B*) and 37 (*a*). During the fatigue test, this specimen worked in the same manner as spot-welded sheets, as lateral bending, during dynamic loading, could be readily observed. The width of the bent part across the specimen has been changed from 1/4 to 3/4 and 1 in. and the number of cycles was recorded for each specimen. These results are as follows:

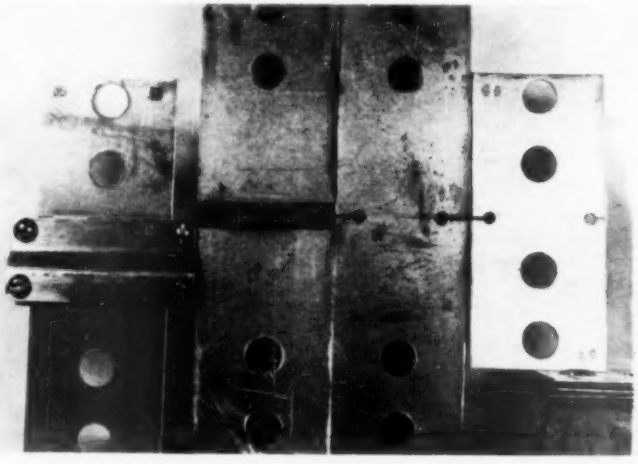
Width of specimen, in.	1	3/4	1/4
Number of cycles	38,900	23,900	4400

After these tests, the same material has been loaded in direct tension without any bending effect by providing straight specimens with small holes and a lateral saw-cut limiting the section of the specimen to 3/4 and 1 in. width. Fatigue tests were carried out with sheets having the same effective section as Specimens 1 and 2 of the foregoing fatigue tests (Fig. 37). These straight specimens under a unit stress of 22,500 and 16,600 psi. repeatedly loaded without any bending effect, showed a number of cycles before failure of the specimens which was about 15 to 30 times greater. This information test showed also that the bending effect combined with repeated tension, reduces the number of cyc'es up to failure by an appreciable amount. This fact, considered from the viewpoint of the low fatigue limit of spot-welded sheets, may throw some more light on this fatigue problem and may give some hints for improving the endurance limit of spot joints.

5.4 Stress Concentration Around the Spot Leading to Failure: Direction and Magnitude of Principal Stresses

5.41 Brittle Lacquer Method; Stress-Coat Analysis of Spots Under Increasing Loads

In order to get some more information about the stress concentration around the spot leading to failure of these thin-welded sheets, the brittle lacquer method was used in a rather preliminary way. The magnitude of the stresses was not measured; this method has simply been used to detect the location of the most stressed zones of the sheets in the neighborhood of the spots. For this purpose, the appropriate lacquer (No. 1203) has been applied to several welded sheets which were gradually stressed under different ways in the universal Baldwin testing machine. During these tests, the brittle lacquer around the spot of the specimen was observed and the load increase was stopped as soon as cracks could be observed over a certain zone near the spot. One specimen was loaded in the usual way without preventing lateral bending while another specimen was loaded using a steel sheath for guiding the sample as described in Section 5.14. As may be seen in Fig. 38, showing at the right a photograph of the two specimens (*b* and *c*) loaded with and without a guiding sheath, the results of this test are in conformity with the microhardness investigation as well as with the stress-strain diagram recorded with specimens loaded under similar conditions. These tests were repeated three times with sheets of 0.03 in. thickness and gave each time practically the same results. Also on an unwelded specimen of the same sheet, the load at which the first crack in the lacquer appeared was recorded. The unwelded sheet material itself yielded under a load of 1300 lb., that is about 29,000 psi., showing suddenly at this load cracks over the sheet in different places



(*a*)

Fig. 37 Specimens of different shapes for fatigue tests (half natural size)

(Fig. 38 (*a*), left). The spot-welded, unguided samples (Fig. 38 (*b*)), however, showed, in simple tension at 750 lb., a very pronounced localized zone of deformation around the spot in the form of an ellipsea, the major axis being placed horizontally. The ellipse itself is not symmetrical with regard to the middle of the spot; it is nearly tangent to the spot at its lower part. A kind of bending of the sheet around a horizontal axis, tangent to the upper part of the spot, is visible. On the other hand, the guided specimen shows a deformation zone of the cracked brittle lacquer which is quite different from that of the unguided specimen. The cracked zone is placed mainly in a vertical position and is more or less symmetrical to the tension axis of the spot. Especially, the compression zone under the spot, under an angle of about 90° (as visible in Fig. 38 (*c*)), seems of importance. This zone is practically nonexistent in the unguided specimen. Furthermore the tension zone in this guided specimen is placed above the

(*a*) (*b*) (*c*)

Fig. 38 Specimens with stress-coat after plastic deformation (0.35 × natural size)

spot and is nearly as great as the compression zone. From the tension zone, two arms, directed at about 45° from the tension axis, spread over the width of the sheet. The total load applied was, in this case, 1094 lb. Of these specimens only two have been photographed, as the brittle lacquer partly fell off, immediately after the test, so that these specimens were not very suitable for photography. Photographs of this type ought to be made immediately after the test without handling the specimen and damaging the lacquer in the cracked zones. All together eight specimens have been analyzed with the brittle lacquer.

5.42 Strain-Gage Measurement in Surrounding Zones of Spot Welds

The stress-coat analysis of spots by the brittle lacquer method gives some useful qualitative information about the stress distribution in and around the spot. However, in order to get more results about the magnitude, location and direction of stresses which are not very accurately revealed by the brittle lacquer method, a further investigation using as many strain gages as possible, placed around the spot in the most important zones, has been undertaken. For this purpose, the smallest size of SR-4 strain gages available has been used. Type A-7 seemed to be suitable, having the following dimensions: effective gage length 1/4 in., net width 2/16 in., resistance 120 ohms. For preliminary tests, four of these gages have been cemented on the 0.03-in. thick specimen around the spot: two in the loading axis, that is one (No. 3) in the tension area on top of the spot and another one (No. 1) in the compression area at the bottom of the weld as near as possible to the periphery of the spot (see sketch on Fig. 41). Two other strain gages have been cemented symmetrically on both sides of the spot near its horizontal axis (Nos. 2 and 4, Fig. 41). Under an increasing load, the indications of the SR-4 recorder have been noted.

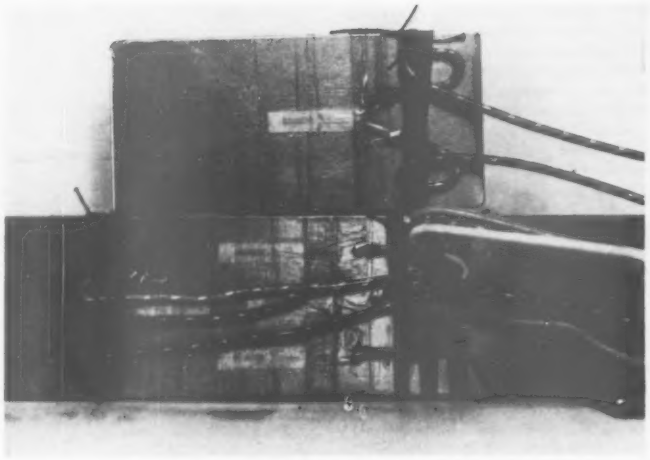


Fig. 39 Specimen and dummy provided with small strain gages (0.8 × natural size)

Table 3

	Strain gage*		
Load, lb.	*No. 3*	*No. 1*	*No. 1*
50	1-1058	3-490	1-404
100	1-049	3-436	1-396
50	1-1058	3-480	1-401
150	1-1050	3-360	1-380
50	1-1057	3-460	1-400
200	1-1060	3-292	1-352
50	1-1053	3-433	1-380
250	1-1075	3-230	1-308
50	1-1051	3-410	1-358
300	1-1100	3-177	1-271
50	1-1050	3-385	1-328
350	1-1124	3-130	1-230
50	1-1045	3-365	1-291
400	1-1165	3-080	1-178
50	1-1050	3-346	1-245
450	1-1215	3-025	1-112
50	1-1058	3-318	1-183
500	1-1271	2-1090	1-010
50	1-1076	3-289	1-090
550	1-1360	2-1025	0-1040
50	1-1110	3-243	0-1125
600	1-1508	2-943	0-863
50	1-1198	2-1268	0-935

* Strain gage No. 4 did not work.

The specimen and the dummy with these special strain gages are shown in Fig. 39 and the setup in the Baldwin machine for making the tests under increasing loads are represented in Fig. 40. Preliminary results with this strain measuring method already give interesting information. The load introduced in the specimen can be separated in tension and compression stresses according to the location of the strain gage around the spot, and the magnitude of these stresses can be measured fairly accurately. The load has been increased gradually, from an initial load of

Fig. 40 Specimens in Baldwin machine

50 lb., in steps of about 100 lb., decreasing the load after each lecture down to 50 lb. The maximum load applied was 600 lb. Some preliminary results are given in Table 3. These results show in the first instance the fundamental difference between the stresses acting in several areas around the spots. One strain gage only, that is, the one cemented on the area right over the spot (No. 3) of the specimen, indicated, starting from loads of over 200 lb., increasing strain under tension and the first permanent deformation of this area seemed to be reached between about 400 and 450 lb.; at this load they increased fairly quickly (Fig. 41). It is curious to note that at loads lower than 150 lb., no strain has been indicated by this gage. Surprisingly, the two other gages, Nos. 1 and 2, indicated strain produced under compression: No. 1 started at about 100 lb. and these strains increased very rapidly, being at 600 lb. much higher in compression than gage 3 indicated at the same load in tension. Also in this area, permanent deformation took place starting at fairly small loads of about 100 lb. and was, after a maximum load of 600 lb., practically as high as the total deformation produced under this load. This means that a flow of the material in compression under the spot takes place producing at each additional load a permanent set which is practically as high as the total deformation itself (elastic plus plastic). Similar results of compression strain were recorded with Gage 2. Provided the indications of these gages are correct, and this has to be checked with several other specimens, it is interesting to note that no tension is acting in the area located on both sides in the horizontal axis of the spot. This can be explained only by a very pronounced bending moment taking place in this part of the welded sheet, producing in compression appreciable plastic strain around the spots. More elaborate tests about this important question have been started at the writing of this paper and will be continued in order to get more information about the local stress distribution around the spot.

6. AMELIORATION TREATMENTS OF SPOTS UNDER NEW LIGHT ON STRESS DISTRIBUTION AND THEIR FATIGUE RESULTS

With the above test results regarding microhardness distribution, Lüder's lines, artificial spots, combined tension and bending tests, as well as the stress analysis around the spot, additional amelioration treatments of the weld were made and their effect checked in the fatigue machines. During the foregoing investigation about the fatigue phenomenon of spot-welded thin sheets, it has been disclosed that the fairly low fatigue limit of these joints is mainly due to combined tension, compression, and bending stresses taking place around the spot in the thin sheet, producing its characteristic failure by cracking.

6.1 Increase of Moment of Inertia in the Plane of Bending

Based on the above experimental observations, it seemed logical that an increase of the moment of inertia in the plane of bending should produce some improvement of the fatigue limit of these spot-welded thin sheets.

For this purpose, different types of embossing processes increasing the moment of inertia of the spot and its environ-

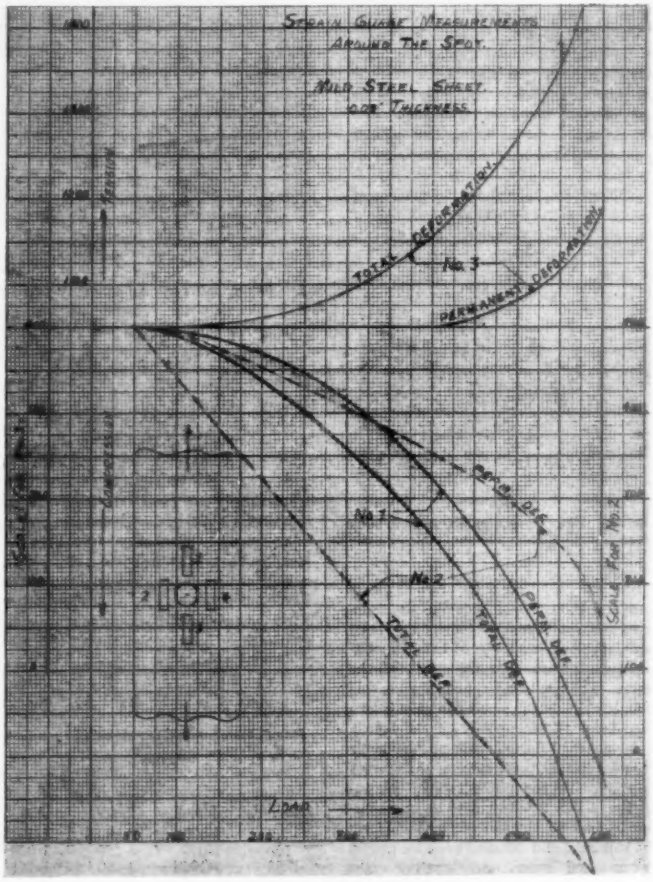


Fig. 41 Diagram of test results with strain-gage method

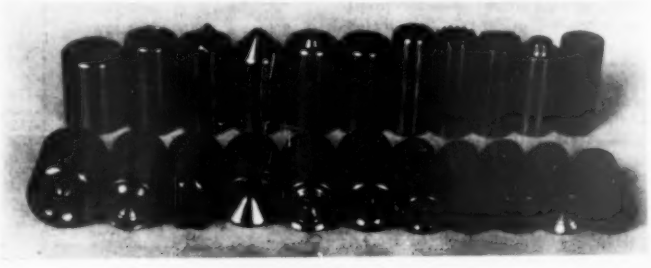


Fig. 42 Compression cylinders of various shapes

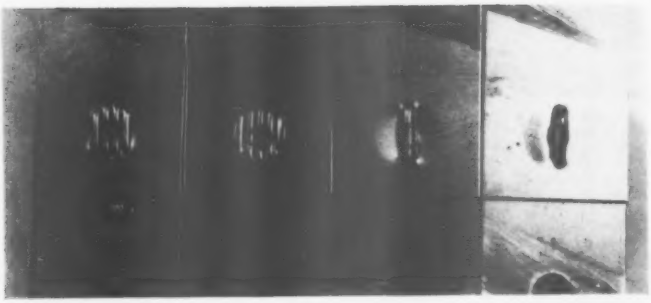


Fig. 43 Specimens after mechanical treatment with different compression cylinders

ments has been tried out in the first place. By compression forces, applied on the spot by different types of rams producing a kind of coining, indenting or embossing, some effect improving the fatigue limit of the spot should be attained. The results of this kind of tests, carried out with 0.03-in. thick welded sheets, are shown in Fig. 44 and the rams for producing different shapes of embossing are represented in Fig. 42 and Fig. 6, *u–w*. Several specimens, after compression with these rams, are shown in Fig. 43. The results, as represented in Fig. 44, show that, with this type of mechanical treatment by special rams of $^5/_8$ in. diameter, no remarkable improvement has been obtained in the fatigue resistance of these specimens. Tested with 500-lb. fatigue loads, they show about 20,000 to 350,000 cycles without reaching much better results than untreated specimens. It is, however, interesting to note that the failure of several of these specimens did not occur in the usual zone immediately adjacent to the spot, but, depending on the diameter of the ram and the embossing produced, the fissure was, in several instances, located about $^1/_8$ to $^1/_4$ in. outside of the usual cracked zone (Specimens 37 and 38). For Specimen 68, the spot has been sheared off and no crack in the sheet is visible.

6.12 Reinforcement of Critical Zones of Failure by the Increased Effective Sheet Section

These tests consisted in producing, by plastic flow of the mild-steel sheet, in the zone of fatigue cracking around the spot, a section which is by a certain percentage, thicker than that of untreated specimens. This has been accomplished with special rams of a diameter of $^3/_8$ and $^5/_8$ in. forming a punch and die in such a way that the material of the sheet is carried away by flowing from the outside zone of the spot toward its border and from the spot the material flows toward the outside border, building up to a certain extent the metal in this zone and thus increasing the cross section of the critical zone of fatigue failure and increasing in the same time the moment of inertia of the spot in the plane of bending. The adjacent zones of the reinforced ring, that is the spot itself and a circular ring zone with an inside diameter of about twice that of the spot, are naturally somewhat weakened in their cross section. This, however, seems to remain without detrimental influence on the fatigue results. Specimens of this type using rams of $^3/_8$ and $^1/_2$ in. diameter are represented in Fig. 45. Contrarily to what could be expected no remarkable improvement of the number of cycles before failure of the specimen could be reported. All mechanically treated specimens of this kind cracked within the number of cycles to failure of untreated specimens in the as-received condition. Diagrams of these results, being without special interest, are not included.

6.13 Displacement of the Area of the Spot Weld Outside the Tension Plane

Along the same line of proposition for the improvement of the spots against repeated loads by increasing the moment of inertia in the plane of bending is the following one concerning the displacement of the area of the weld outside of the plane of the joint. This proposition aimed at the possibility that the spot, placed by plastic deformation outside of the plane of the sheet, may show some improvement of its fatigue resistance. It seemed possible to apply a higher number of cycles before failure on a spot of which the shear stresses are partly converted into compression stresses between the two sheets pushed plastically outside of the plane of the sheets. Depending on the degree of cupping, with the spot in the bottom of the cup, not only the shear stresses in the spot ought to be appreciably reduced, but also the stiffness of the weld should be increased preventing more readily the bending effect at each load application in tension. In order to find out if this proposition might bring a higher number of cycles, the spot and its environments were, by means of rams of various diameters and deepness, plastically pushed out of the sheet by a kind of deep drawing process combined with a compression of the spot between the ram and the die. Some specimens, after the cold-working process and the fatigue tests, are shown in Fig. 46. These results are interesting in so far as they indicate that this treatment of the spot, although logical and promising for an increase of the number of cycles, did not bring an improvement of the fatigue resistance.

6.2 Effect of Discharging Transverse Holes in the Tension Zone of the Spot

Based on the results obtained by the brittle lacquer method, the microhardness tests as well as the strain-gage measurements of the stress distribution in a simple spot-welded thin specimen, showing that, due to bending, the zone immediately above the spot is loaded by fairly high-tension stresses combined with bending stresses, taking place in this part of the weld, the following specimens have been prepared and tested. It seemed useful to rearrange the stress distribution around the spot in such a way that the harmful combined stresses (tension and bending), especially in the tension zone of the spot, be reduced, while the stresses on the opposite side of the weld, where prevailingly compression stresses are active, may be increased. For this purpose, different kinds of discharging holes have been provided in the welded sheets, as is shown in Fig. 47. The width and distance of these discharging slots from the spot area have been varied and fatigue tests carried out with these specimens. Again these test results are mainly of a negative character; in no case an improvement of the fatigue resistance, indicated by a higher number of cycles before cracking, could be recorded. It is, however, of interest to note that, according to the width of these holes, the failure did not take place near the spot, but frequently in the section where the sheet has been weakened by the slots. This means that the main tension stresses which are active in the center of the sheet above the spot were reduced so that no crack in the neighborhood of the spot could be observed.

6.3 Prevention of Bending of the Specimens Under Repeated Loads

According to the static tension tests carried out with guided welded specimens as described in section 5.14 (Fig. 29), showing that, by prevention of the bending of the specimen under simple tension, a much higher proportional limit as well as an increase of the maximum load could be measured, these guided specimens were tried out under repeated loads to see how they behaved. For this purpose, specimens of 0.03 and 0.04 in. thicknesses were tested in the Krouse fatigue machine under repeated loads of 500 and 600 lb., by using a special steel sheath. Figure

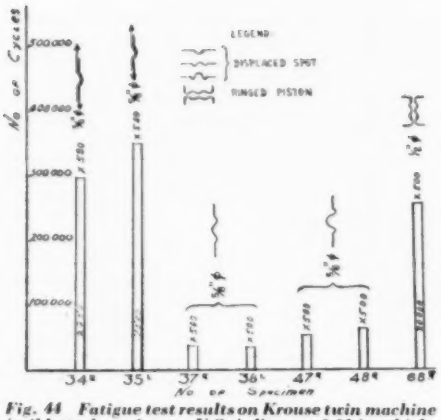


Fig. 44 Fatigue test results on Krouse twin machine (mild-steel specimen: U.S.A. Factory 0.03 in. thickness)

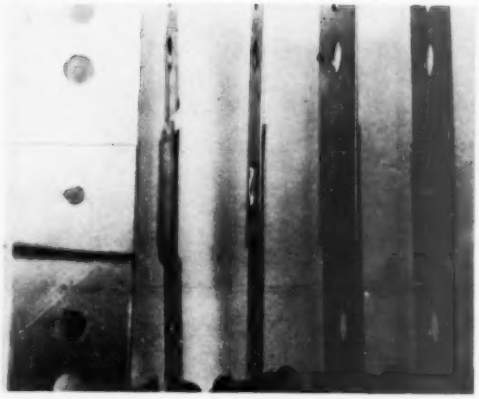


Fig. 46 Specimens with displaced weld outside of tension plane

48 (left) shows the sheath as used for these tests. These test results show that in conformity with the static tests, the fatigue resistance of the guided specimens is much higher. For instance, 0.03-in. specimens had a remarkable increase of the number of cycles (about 1.5 to 2.6 million cycles without cracking at a load of 500–600 lb.). Also thicker specimens of 0.04 in. under a load of 500 lb. supported with the guiding sheath a much greater number of cycles than the unguided specimens, as this is shown on the left of Fig. 49. These test results prove the basic importance of the bending effect taking place under repeated fatigue loads in relation to the endurance limit of these thin spot-welded joints. If bending stresses are avoided, a much higher fatigue limit of the welds can be expected. Other arrangements, using, instead of a sheath, stiff rectangular guiding plates, fixed by two screws over the spot or sheets of 0.03 in. thickness, and acting as restrainers for prevention of bending of the specimen, right part of Fig. 48, were also more or less successful during these tests. It is evident that this arrangement for testing specimens is without greater practical significance, but it gave us some hints regarding the combined tension and bending stresses taking place in the spot area which are greatly responsible for the lower fatigue limit of thin spot-welded joints.

6.4 Other Test Results of Different Types of Mechanical Treatment

In this paragraph are reported all specimens tested under fatigue loads which are not referred to in the preceding sections. Besides the fairly great variety of treatments carried out with spot-welded thin mild-steel and stainless-steel specimens, as described in this report, there have been made several other series of fatigue tests with specially treated samples. The specimens have been treated mainly under high hydrostatic pressure before testing on the fatigue machines. Especially, the influence of the different compression faces of the rams of various diameters on the endurance limit of the spot welds has been studied. As may be seen by Fig. 49, right side, the number of cycles applied to several specimens, tested on Pulsators I and II, could be increased appreciably before failure took place; the testing conditions were the same as for untreated specimens. All samples had a thickness of 0.039 in. As already indicated by several preceding tests, fairly good results have been obtained with compression rams of $^2/_3$ in. diameter, with compression faces of corrugated or lined pattern (Fig. 6 (*l*)) placed either in a transverse or longitudinal direction to the loading axis of the specimen. Under compression loads of 20,000 lb. and fatigue loads of 750 to 780 lb., the number of cycles was fairly high; all specimens supported over 1.5 million and most of these welds could be loaded for about 2 to 3.5 million times without failure, Fig. 49 (Specimens 29, 31, 33, 37, 38 and 39). Also, specimens compressed with rams of the type *k* and *m* (Fig. 6; see also Fig. 6 (*A*) and 6 (*B*)), under 20,000 lb., showed similar results (see Specimens 32, 34 and 35 on Pulsator I, and 36, 41 and 42, on Pulsator II). It is of interest to note that similar results, showing an analogous high increase of the number of cycles, after the amelioration treatment, have been reported in Figs. 5, 7 and 10 for mild steel of 0.030 in. thickness compressed with $^1/_4$-in. diameter rams and for $^1/_2$ hard stainless-steel specimens, according to Fig. 16. This treatment seems to be of special interest for improving the fatigue resistance of spot-welded specimens.

7. SUMMARY OF FINDINGS

According to the test results described in sections 3 to 6, the following findings have been made during the course of this investigation:

1. Untreated spot-welded mild-steel specimens of 0.03, 0.039 and 0.04 in. thickness show under pull-pull fatigue tests a fracture which is invariably placed in an adjacent zone of the top of the spot starting in the length axis of the specimen and spreading on both sides around the spot in a transverse crack (Fig. 3).

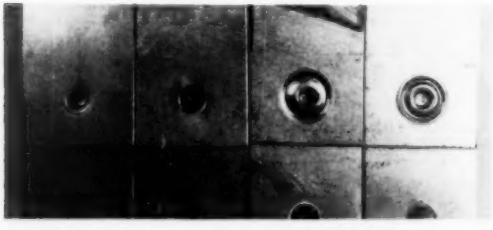


Fig. 45 Specimens with reinforced ring zone

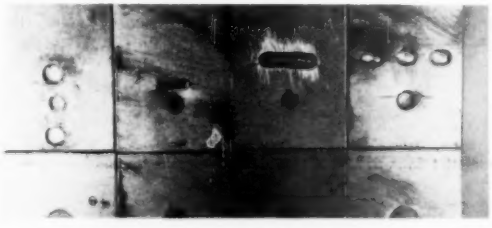


Fig. 47 Discharging holes in specimens

2. Under high compression loads of about 15,000 to 20,000 lb., applied with a ram of 1/4 in. diameter, representing a maximum of about 400,000 psi., an improvement of the number of fatigue cycles of 2 to 3 times has been recorded on two different pulsators under pull-pull loads of 500 to 760 lb., applied to welded mild-steel specimens (Fig. 5). Similar results have been obtained on a Krouse fatigue testing machine (Fig. 9).

3. The number of cycles up to failure of mechanically untreated mild-steel specimens, under fatigue loads of 650 to 680 lb., is of the order of 50,000 to 130,000 cycles; low-alloy steel specimens, of the same dimensions, showed, in the as-received condition, an appreciably higher number of cycles under an about 20% higher fatigue load (Fig. 5).

4. Thin welded sheets of 0.03 in. behaved under fatigue loads in a similar way to the 0.04 in. thick sheets; the number of repeated loads for untreated specimens was about the same as for the thicker specimens, only the load was lower; under 500 lb. about 100,000 to 120,000 cycles were necessary for failure. Heat treatment by annealing reduced the number of cycles appreciably. By a hydrostatic pressure of about 20,000 lb. the number of cycles of these specimens could be increased about 5 times by using rams of 3/8 in. diameter with special corrugated end faces (Fig. 10).

5. Stainless steel specimens 18–8 of 0.03 in. thickness, 1/4 hard, tested on two different fatigue machines, supported a higher repeated load up to failure than mild-steel specimens; under 650 to 770 lb. the treated specimens were generally more resistant and, according to the mechanical treatment, cycles of 3 to 10 times those of untreated specimens could be recorded. Rams of 3/8 in. diameter (Fig. 6 (*k*)), pressed with 20,000 lb. against the spot, produced this amelioration (Figs. 12 and 14).

6. Stainless-steel specimens of 0.03 in. thickness, in 1/2 hard condition, as tested in two different pulsators, showed improved fatigue cycles after compression with a 1/4-in. diameter ram, with engraved parallel lines placed in a transverse direction to the loading axis and in a position giving an interlocked effect on the spot. Under repeated loads as high as 750 lb. and up to 820 lb., a few million cycles could be recorded before failure took place (Figs. 15 and 16).

7. By Vickers microhardness tests made on the surface and in the section of welded samples, the hardness topography of the weld and its environments showed an appreciable increase over a very short distance around the spot, having a maximum in its center. Lüder's lines spread over the surface of strained joints confirmed the microhardness pattern laid down in a three-dimensional presentation of the results. Specimens stressed without and with a guiding sheath showed a fundamental different microhardness model of the spot surroundings. The hardness in the strained material corresponding to Lüder's lines is about 20% higher than that in unstrained mild-steel specimens.

8. By guiding welded specimens in a sheath, the proportional limit of the joint as well as the maximum load producing plastic deformation can be increased by about 40 to 50%; the total energy absorbed by the plastic deformation zone around the spot is a few times greater if loaded with a sheath than under free tension of the specimens in the testing machine.

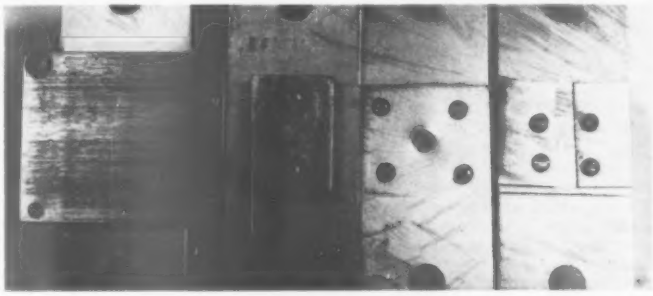


Fig. 48 Prevention of bending of specimens by guiding sheath and restrainers

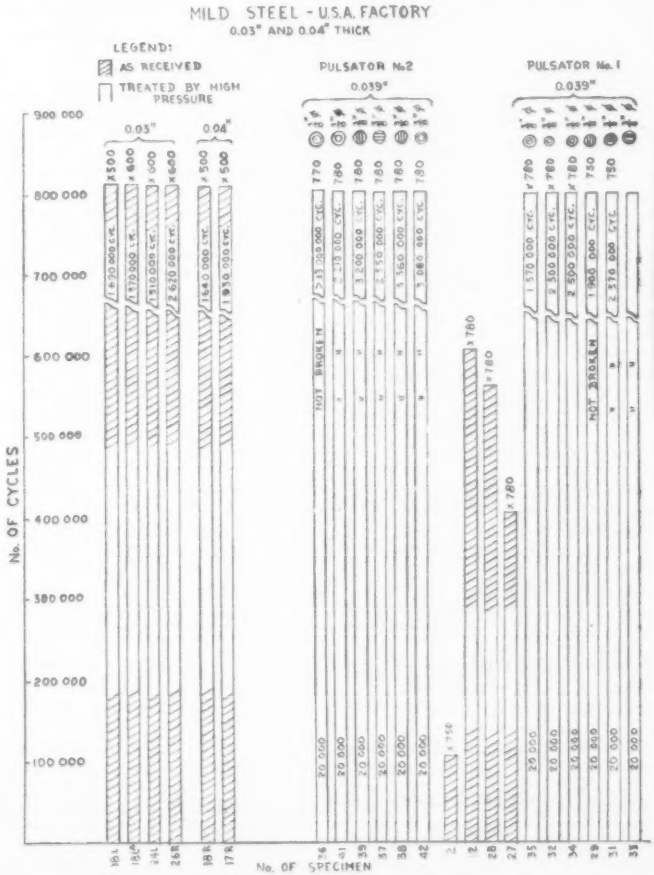


Fig. 49 Test results of guided, unguided and mechanically treated specimens

9. By an artificial spot, joining two mild-steel sheets of 0.03 in. thickness over an area corresponding to that of an ordinary spot without using any heat, it could be shown that the so-called heat-affected zone around the spot does not weaken its fatigue resistance. Failure by cracking has taken place after about the same number of cycles as resistance welded sheets. The characteristic shape of the crack, spreading first around the spot then horizontally in a transverse plane through the sheet, has been obtained just as with joints made on a spot-welding machine.

10. Also by combined tension and bending fatigue tests, stresses being introduced into the sheets by a special shape of the specimen, it could be shown that the combined stresses reduce appreciably the cyclic loads of these specimens before failure.

11. The low fatigue resistance of spot-welded mild-steel sheets is very likely due to a combination of tension and bending stresses rising to a fairly high amount exactly in the zone adjacent to the spot on the tension side of the applied load.

12. By the brittle lacquer method, the fundamental difference in the behavior of the spot welds under simple tension and those laterally supported by a guiding device could be shown. The zone of plastic deformation is in both cases fundamentally different and the low-energy absorption of the surroundings of the spot become clear. The free tension test puts the sheet under appreciable combined bending and tension stresses.

13. Strain-gage measurements in the neighborhood of the spot under tension, revealed, by preliminary test results, a stress distribution which, in the axis of the specimen above the spot, is, in tension, smaller than the compression stress taking place under the spot in the same axis. About the bending stresses, no definite method has yet been elaborated which might reveal accurate values of this type of stress.

14. Different types of embossing, coining and indenting, under loads of 15,000 to 20,000 lb., applied in the region of the spot, contrary to what could be expected, did not bring an important amelioration of the fatigue resistance of these specimens.

15. Also a reinforcement of the critical zone of failure, by increasing the effective metal section around the spot, was not successful regarding an appreciable increase of the fatigue resistance.

16. The variation of the diameter of plastically strained spots, as well as the displacement of the welded zone outside of the tension plane, did not bring the expected increase of the fatigue resistance of the spots. Some of these specimens showed that the failure of the sheet by cracking does not take place in the heat-affected zone around the spot, but in an area located far outside of the weld which is highly stressed under combined tension and bending.

17. Discharging holes in the tension zone of the sheet did not have an effect on the increase of the cyclic loads of 500 lb.; they showed, however, that after 20,000 to 40,000 cycles, the fracture of the specimen has been displaced in several cases from the so-called heat-affected zone around the spot to the ends of the discharging holes placed in the tension area of the weld. The spot, under this arrangement, did not receive mainly tension stresses in its upper part, but compression stresses acting underneath the weld which are less dangerous.

18. By using special guiding sheaths placed with sufficient free play for a frictionless displacement of the stressed end of the joint, it has been shown that the number of cycles could be appreciably increased before failure took place in the usual way by cracking. In some cases, even under loads 20% higher, the failure occurred only after 1.5 to 2.5 million cycles. This improvement is mainly due to the prevention of bending of the specimen in the area adjacent to the spot.

19. The most effective mechanical treatment for a higher fatigue resistance of spot-welded thin mild-steel sheets seems to be possible by the impression of $^1/_{\text{e}}$ and $^3/_{\text{e}}$-in. diameter rams with lined, crossed, interlocked or circular compression areas under hydrostatic pressure of 20,000 lb., representing about 200,000 to 400,000 psi. on the area of the spot. Under fairly high fatigue loads of 750 to 780 lb. a repetition of several million cycles was possible without failure of the spot in its environing zone.

20. From the preceding preliminary findings, concerning the stresses acting around the spots, of which the bending stresses seem most important, it has been deducted that a serious increase of the amount of inertia of the weld in the plane of bending could help greatly to raise the endurance limit of these joints. In connection with this statement, the following proposition, concerning the shape of the spot, seems of interest. Instead of a joint consisting of a welded area represented by a circular section having a diameter of about $^1/_4$ in. for these thin sheets, it seems logical to change this area and make a more appropriate distribution of the bonded metal. In this respect, the fatigue properties of spot welds might be fundamentally changed if, instead of the section of the spot used at present, a section, represented for instance by a ring having about the same area, would be used. This hollow circle section will spread the bounded metal area away from the center of the spot in an area of greater diameter, having an increased moment of inertia in all directions and consequently supporting a higher fatigue load than the welds of the actual shape. It cannot be judged if there will be difficulties in making such hollow circle welds. However, if this can be done, it is not without confidence that specimens of this type, having different outside and inside diameters of the hollow spot, would be tested in the pulsators installed in this laboratory in order to compare their endurance limit with that of the usual type of spot welds with an area of circular bounded metal. It is evident that this new type of spots may have a geometrical form other than that of a hollow circle, as for instance, having small radial arms in form of a star or any other, if this can give some higher fatigue resistance to these welds. The suggestion is to make a small series of hollow spots with increasing diameter in order to verify their endurance limit in comparison to that of the standard type of welds.

SUGGESTIONS FOR FURTHER RESEARCH

The following suggestions are made for further research work to be carried out on the fatigue resistance of spot welds:

1. The fundamental investigation about localized stress and strain distribution around the weld should be continued. Especially the strain-gage measurements under increasing static loads applied to specimens with and without prevention of lateral bending, should be continued; this method eventually combined with discharging holes might give a possibility to study the flow of stresses around the weld in more details.

2. Tests to find out the best possible effect of the hydraulic compression treatment should be completed and the final *S–N* curves for one or two types of mechanically treated specimens, showing the increase of the fatigue load in the whole range of a few hundred to several million cycles of treated and untreated specimens, should be carried out. Before these final tests will be started, it seems, however, advisable to make some more preliminary tests in the range of about half a million to 2 to 5 million cycles, in order to be sure not to overlook a possible improvement of the fatigue limit in the very low ranges by the used mechanical treatment. Two different kinds of steel (mild steel and stainless steel 18–8) of two different thicknesses (0.03 and 0.04 in.) and eventually the influence of the spot diameter on treated and untreated mild-steel specimens should be studied.

3. The same tests should be carried out with Alclad aluminum alloy sheets 24ST; preliminary tests with this material have been described in paper 1.

4. Apart from this main research program, other smaller investigations concerning further amelioration treatments will be tried out; based on such results, new suggestions can eventually be made for further improving the spot welds of thin aluminum alloy and steel sheets.

Electrode Coatings Containing Rutile

Properties of weld-metal tests of experimental electrodes containing approximately 40% rutile were found to be directly influenced by the rutile component. Arkansas rutile in the electrode coating produces weld metal with higher strength and lower ductility than electrodes containing commercial rutile

by R. D. Van Zante, T. R. Graham and R. G. Knickerbocker

INTRODUCTION

ONE phase of the Federal Bureau of Mines research program on marginal reserves of our mineral resources has been a utilization study of the mineral products of these deposits. This report presents the progress of an investigation concerned with the usability of rutile concentrates made from the titania ores of the Magnet Cove district in Arkansas in the coating of arc-welding electrodes. Comparisons have been made on the electrode performance and mechanical properties of experimentally prepared welding rods in which various rutile products were used in the coating. It will be apparent that the study is in the nature of a preliminary investigation which indicates the necessity of a more detailed study of certain phases of the general problem.

The report is offered at this time in the hope that it will invoke general discussion and commentary which will serve as a guide to future investigations on the fundamentals of rutile and other materials used in electrode coatings. The influence of these materials and the mechanisms in metal transfer may be known by electrode manufacturers and various research organizations, but they have not been given full consideration in published work. The data in the present report present fundamental differences in the mechanical properties of all-weld-metal specimens which are directly influenced by the rutile component used in the electrode coating.

SUMMARY

1. Under the conditions of the present investigation, all-weld-metal test specimens made with Arkansas rutile concentrates in the electrode coating are inferior to similarly produced weld metal from arc-welding rods containing commercial rutile in the coating and to commercial electrodes.

2. The mechanical properties of metal deposited from Arkansas-rutile-coated rods exhibit higher strength and lower ductility than weld metal from electrodes coated with commercial rutile.

3. Several individual weldments made with Arkansas-rutile-coated electrodes were found to conform to the A.W.S.-A.S.T.M. requirements, although the average values from numerous tests are on the border line of the 17% minimum elongation and place the welds in a questionable category.

4. Sulphur content of the Arkansas rutile samples used in formulating the experimental electrode coatings ranged from 0.024 to 1.06%. Reduced ductility of the weld metal was indicated throughout the range in varying degrees. With 0.20% sulphur and less in the rutile concentrates used to make up the coating, the effects of this impurity were obscured by factors not definitely identified or evaluated. Above 0.20% sulphur, both the performance of the electrodes during welding and the physical qualities of the deposited weld metal were unsatisfactory.

5. Commercial rutile, to which pyrite was added as an impurity in quantities equivalent to 0.09 to 1.06% sulphur, was used for the titania constituent of experimental electrode coatings. An embrittling effect on the deposited weld metal was indicated throughout the entire range; but at 0.20% and below, the comparative effects were so small as to be inconclusive. At 0.33% and higher, both the performance of the electrodes during welding and the physical qualities of the deposited metal were unsatisfactory.

6. Comparisons were made between electrode coatings carrying equal sulphur contents. In one case the impurity was present as a normal constituent of Arkansas rutile, and in the other as the deliberate addition of fine ground pyrite to commercial rutile. Pyritic sulphur added to commercial rutile was less effective than an equivalent amount of naturally associated sulphur in the Arkansas rutiles on the mechanical properties of the weld metal.

7. So far as the results of the investigation disclose, the presence of phosphorus in the Arkansas rutile in quantities up to 0.29% exerted no deleterious influence on the performance characteristics of electrode coatings formulated from this material.

8. Analytical studies detected no significant concentration of sulphur in weld metal until the sulphur content of the rutile from which electrode coatings were made reached 1.06%.

9. The stress-relieving treatment in trials involving the use of Arkansas rutile was normally effective in the great majority of cases. In the isolated instances where this was not true the causes are obscure and possibly attributable to factors not related to the coating constituents, so far as the investigation discloses at the present time.

R. D. Van Zante and T. R. Graham are Metallurgists and R. G. Knickerbocker is Chief at the Rolla Branch, Metallurgical Div., Bureau of Mines, Rolla, Mo.

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Acknowledgment is made to L. H. Clarke, formerly of the Rolla Branch, now in the Fuels and Explosives Division, who carried out the initial phases of the investigation, and to Heine Kenworthy, metallurgist of the Rolla Branch, who rendered assistance at one stage of the work.

GENERAL

The deposits of titanium minerals that occur in Arkansas are extensive and accessible. The products from intermittent attempts to work them have been difficult to market domestically and virtually excluded from a most important use for rutile, that is, in the coatings for arc-welding electrodes. Various explanations for this situation expressed by users and purveyors of this product did not agree, nor were any factual data available as to

the deficiencies or disadvantages peculiar to these minerals.

Nevertheless, these deposits represent a potential domestic source of a mineral commodity whose importance has increased proportionately with the growth of welding. It therefore appeared desirable to supplement existing knowledge regarding the extent, nature, beneficiation problems and utilization of the products of these ore bodies. One aspect of the utilization studies was the investigation into the use of suitable products in welding-electrode coatings. The plan followed was to use samples prepared by the Mineral Dressing Section for the titania constituents of experimental electrode coatings and to compare the performance of these electrodes with (1) A.S.T.M. specifications, (2) commercial electrodes of the same type, (3) experimental electrodes in whose coatings Arkansas rutile was replaced by commercial rutile and (4) each with the other.

PRELIMINARY WORK AND PROCEDURES

The special equipment ordinarily used for coating electrodes by extrusion was not available. It was necessary to develop a technique for applying the coatings by hand dipping. After a period of experimentation, it was judged feasible to produce satisfactory coatings by this method in the quantities required for the investigation. The steel cores of commercial E-6012 rods, stripped of their coating, were used in this investigation. The wire analysis was found to average 0.15 carbon, 0.035 sulphur, 0.018 phosphorus and 0.22% silicon. The established procedure in preparing the experimental coverings consisted of conditioning a slurry of the coating components to a suitable consistency for adhering to the bare wire without running. Two dips, each followed by an air-drying period of several hours, were found most satisfactory. Proper technique would produce a smooth, concentric coating of about 6.5 to 7 gm. weight on a $^5/_{16}$- by 14-in. wire, which is approximately the weight of coating on some popular brands of commercial type E-6012 electrodes. The final air-drying period was followed by a baking treatment during which temperature was gradually raised to 300° F. over a period of 6 hr. and held at that level for 2 hr.

The drying treatment proved to be satisfactory to the extent that properly prepared experimental electrodes dried by this procedure exceeded requirements as to performance and character of the deposited weld metal. It was therefore adopted as standard, although the fact that it probably did not represent the optimum was thoroughly appreciated. The principal consideration was to standardize on a given set of conditions and thereby eliminate the drying treatment as a variable from the experimental procedure.

Manufacture of electrodes is highly competitive, and each producer's position depends on keeping abreast of the field. Considerable effort and expense are devoted to development work, particularly in coating formulas. Available information on this phase of arc welding is usually fragmentary and incomplete. Preliminary to making an attack on the problem it was therefore necessary to conduct a series of experiments toward the development of coating formulas, using standard commercial rutile as the titania constituent. The mild-steel type E-6012, a titania-coated electrode, was selected as the most convenient comparison standard. With the welding production established in the postwar period, the demand for this type electrode is greater than for all others. The E-6012 electrode is often referred to as a general-purpose electrode because of the various applications of the rod in light and heavy structural work and in maintenance repair. In most formulations, the rutile in the coverings of these electrodes is more than 35% by weight. Other ingredients are likely to include aluminum silicates, ferromanganese, cellulose and calcium and potassium compounds, with sodium silicate as the binder.

From the preliminary work two formulas were adopted for the more detailed investigation. These two mixtures, designated "A" and "B" in Table 1, are both typical of the general type E-6012 in composition. Commercial electrodes, however, use less binder, since they are extruded rather than dipped.

Table 1—Experimental Coating Formulas

Ingredient	*Formula, %* *A*	*B*
Rutile	41	41
Calcium carbonate	5	3
Asbestos	5	..
Mica	..	7
Feldspar	..	9
Kaolin	9	5
Magnesite	2	2
Ferromanganese (80% Mn)	10	10
Flour	2	2
Soda ash	1	1
Sodium silicate (N grade, 38%)	25	20

Electrodes coated according to Formula A performed in a manner comparable to the commercial counterpart. Those according to Formual B were a quieter, easier-handled, smoother-acting electrode and were believed to approximate in performance the commercial type E-6013. These formulas, while not necessarily comparable in every particular to those in use commercially, were nevertheless satisfactory for the purpose of making comparisons between various rutiles, and one or the other is the medium of comparison in the experiments subsequently reported.

Comparisons between electrodes were made on the basis of the requirements of A.W.S.-A.S.T.M. specifications for arc-welding electrodes, Serial Designation A233–45T, with particular reference to the all-weld-metal tension test as described therein. Briefly, the procedure consists of preparing a welded joint of such size and shape that a standard tensile specimen can be cut from the weld metal and applying the standard tension test to the specimens for the determination of ultimate tensile strength, yield point and elongation, in both the as-welded and the stress-relieved conditions. More recent A.W.S.-A.S.T.M. standards have eliminated the stress-relieved property requirement and have increased the minimum as-welded strength specification to 68,000 psi., with an elongation of 17% in 2 in. The individual test specimens were broken in tension within 6 to 8 days after weldment. Since this class of rod has been reported to produce considerable hydrogen in the welds, which in turn have a bearing on the resultant properties, standardizing on the time factor reduces the probability of additional variables.

The number of variables involved in making these comparisons, not the least of which is the human element in preparing the welded test plates, inevitably produce scattering in the results from duplicate tests. A.W.S.-A.S.T.M. standards recognize this tendency and provide for a second determination of the physical qualities of the metal if the first trial fails. Results presented in this report are averages of groups whose individual deviations from the norm, after making due allowance for the inherent tendency to scatter, do not contradict the major indication.

Since the purpose for which these formulas were developed was a comparison vehicle rather than the production of an electrode comparable to the commercial article, the guided-bend and fillet-weld usability tests were not made. However, repeated informal trials on both a.-c. and d.-c. current, and in the flat, horizontal, overhead and vertical positions, were made by several experienced welders, and it was agreed that the usability characteristics of the electrodes coated according to the experimental formulas were excellent.

A comparison, based on the standard all-weld-metal tension test for arc-welding electrodes, between A.W.S.-A.S.T.M. minimum requirements, the metal from commercial type E-6012 electrodes deposited and tested under exactly duplicated conditions and the metal from experimental electrodes of coating formulations A and B is presented in Table 2. Results are shown for the not-stress-relieved and stress-relieved conditions, designated, respectively, *NSR* and *SR*. Rutile from a commercial supplier was used in the preparation of the experimental coatings.

Reliability of the experimental procedures was confirmed by the fact that the weld metal deposited from commercial electrodes was well above A.W.S.-A.S.T.M. requirements. Using these results as

Table 2—Comparison of Physical Properties of Weld Metal

Property	A.W.S.-A.S.T.M. minimum requirements NSR	SR	Commercial type E-6012 electrode NSR	SR	Experimental electrode, Formula A NSR	SR	Experimental electrode, Formula B NSR	SR
Yield point, psi.	52,000	47,000	64,150	61,500	65,500	58,150	67,300	64,700
Tensile strength, psi.	62,000	60,000	76,600	71,200	76,500	70,100	79,700	76,600
Elongation, per cent in 2-in.-gage length	17	22	18.6	24.3	19.6	25.2	17.3	23.0

Table 3—Chemical Analysis of Rutile Samples

Constituent, %	Commercial-type rutile	Arkansas rutiles S-1	S-2	S-3	S-4	S-5	S-6
TiO_2	92.55	94.00	92.44	95.30	92.10	92.20	92.59
Fe	1.09	1.26	2.86	...	1.90	1.40	2.74
SiO_2	2.33	<0.05	1.28	...	0.79	0.63	1.56
Zr	2.13	Nil	...	...	...	...	...
S	0.02	0.20	1.06	0.33	0.20	0.09	0.024
P	0.06	0.095	0.09	...	0.05	0.29	0.01
CaO	...	...	...	...	...	0.52	0.06
Al_2O_3	...	...	...	...	...	...	0.36
Cr	<0.05	0.06	...	...	...	...	<0.05
V	<0.05	0.32	...	...	...	0.34	0.24
Cl	...	0.01	...	...	...	...	...
F	...	0.07	...	...	...	...	...
Zn	...	Nil	...	...	...	<0.05	0.17

the basis for comparison, experimental electrodes with coating Formula A produced weld metal of comparable or superior properties. Those with coating Formula B also produced metal exceeding A.W.S.-A.S.T.M. requirements but by a narrower margin. In the numerous tests, as-weld test specimens made from Formula B invariably produced slightly higher strength properties and lower ductility. While these differences are not great, they are quite consistent and amount to approximately 3000 psi. for the tensile strength and about 2% for the elongation values. In performance the advantage was with Formula B; in physical character of the deposited metal, Formula A was best. Both, however, were capable of meeting A.W.S.-A.S.T.M. requirements and were satisfactory for the purpose intended.

With completion of the proof tests for procedure and experimental technique, the investigation was directed to a comparison of the Arkansas rutiles and commercial rutile as a constituent in electrode coatings using the two formulas developed in the preliminary work.

COATINGS CONTAINING ARKANSAS RUTILES

Six individual lots of concentrates prepared from the Arkansas ores were available for this investigation. Some of these products were obtained from previous beneficiation experiments, and others were especially prepared by the Mineral Dressing Section of the Rolla Branch of the Bureau of Mines. The respective analysis of these lots is given in Table 3. Details of the beneficiation procedures for the rutile are described in published reports.[1,2] As a basis for comparison, the analysis of the commercial rutile used in the formula-development tests is included in the tabulation.

It will be noted that fundamental differences based on the genetics of the ore deposits exist between the commercial and the Arkansas rutiles. Also a considerable range of constitution occurred from sample to sample in the Arkansas rutiles. Variations for any particular constituent depended principally on the nature of the processes employed in the preparation of the product. A uniform characteristic of the Arkansas samples is the 92% plus titanium dioxide content. The principal differences between the commercial type of rutile and the products of the Arkansas deposits are the higher iron, sulphur, vanadium and phosphorus contents of the Arkansas rutile. The commercial product is similarly higher in Zr and SiO_2. In a comparison of these materials in electrode coatings, it should be noted that the coating usually represents approximately 15% of the total weight of the rod. The titania content, in the case of the formulas in this investigation, is about 6% of the total weight of the electrode. Hence, assuming no losses in the arcing process, elements present to the extent of 0.5% in the rutile would be 0.03% in the deposited material.

Coincidentally with completion of the work on formula development, a preliminary experiment was made on the use of Arkansas rutile. The only sample of this product available at the time was sample S-1, which represented a small amount of material prepared by special methods. This sample, and commercial rutile, were used for the titania constituent of the coatings of two comparable lots of experimental electrodes. Coatings were prepared according to a preliminary formula which represented a step in the development of Formula A.

Table 4 presents the results from tension tests on all-weld-metal specimens from these electrodes. As a basis for comparison, A.S.T.M. minimum requirements and comparable data from commercial electrodes are also shown.

These data, while preliminary in nature, indicated that electrodes having Arkansas rutile in their coatings were capable of depositing metal exceeding A.W.S.-A.S.T.M. minimum requirements for physical properties. The metal was somewhat less ductile than that from duplicate electrodes with commercial rutile in their coatings and also less than the metal from commercial electrodes. At this stage of the work these indications were regarded as encouraging.

As the other samples of Arkansas rutile became available, they were used as the titania constituent of experimental electrodes. Table 5 presents the results from a group coated according to Formula A, using samples S-4, S-5 and S-6 as the titania constituents. Included in the tabulation for comparison purposes are A.W.S.-A.S.T.M. minimum requirements and comparable data from experimental electrodes, the coatings of which were duplicates except for the substitution of commercial rutile for Arkansas rutile.

Weld metal exceeding minimum requirements was deposited from the electrodes coated with the formulation con-

Table 4—Comparison of Physical Properties of Weld Metal

Property	A.W.S.-A.S.T.M. minimum requirements NSR	SR	Commercial type E-6012 electrodes (from Table 2) NSR	SR	Experimental electrodes, preliminary coating formula: Containing commercial rutile NSR	SR	Containing S-1 Arkansas rutile NSR	SR
Yield point, psi.	52,000	47,000	64,150	61,500	61,700	50,500	67,900	62,200
Tensile strength, psi.	62,000	60,000	76,600	71,200	71,900	64,400	77,600	71,900
Elongation, per cent in 2-in.-gage length	17	22	18.6	24.3	20.3	22.6	17.2	22.6

taining S-4 Arkansas rutile. Compared with the duplicate electrodes containing commercial rutile, a small loss in ductility and a corresponding increase in tensile properties were indicated, and a slightly reduced effectiveness for the stress-relieving step.

The data for the S-4 and S-5 rutile electrodes give tensile strengths of 78,200 and 81,200 psi., respectively, which is somewhat higher than the standard rods containing commercial rutile. The elongation values for these rods are of the same general order as the commercial rutile electrodes. The S-6 specimens compare favorably in strength but were consistently low in ductility, averaging about 2% less than similarly processed commercial rutile rods. The yield-strength properties show similar trends. While the experimental rods respond to the stress-relieving treatment, the decrease in strength and increase in ductility are definitely less than was noted for the control specimens made with commercial rutile.

No outstanding advantage was apparent in these rutile products, although from the reduced sulphur content of S-5 and the reduced sulphur and phosphorus contents both of S-6 such an advantage might logically have been expected.

Lots of experimental electrodes were also prepared according to Formula B, using samples S-2, S-3, S-4, S-5 and S-6 of Arkansas rutile as the titania constituent of the coatings. Results from these electrodes are shown in Table 6, together with A.W.S.-A.S.T.M. minimum requirements and comparable data from duplicate electrodes with commercial rutile in the coating.

The results from the B-formula coatings containing Arkansas rutile were definitely inferior to the duplicates containing commercial-grade rutile, and in no case met A.W.S.-A.S.T.M. minimum requirements.

The tensile strength of weld metal made from the Arkansas rutile electrodes was found to be in excess of 80,000 psi., with elongations considerably less than the minimum A.W.S.-A.S.T.M. requirements. The as-welded or not-stress-relieved test specimens varied from 9.4 to 15.1%. It will also be noted that the stress-relieving treatment increased the ductility substantially, but in all instances the average values were less than the control samples made with commercial rutile. The ductility was also less than the minimum acceptance requirements. Ductility in inverse ratio to the sulphur content of the rutile was noted in samples S-2, S-3 and S-4, but the relation did not persist through the lowest sulphur samples S-5 and S-6. One or more factors other than sulphur evidently exerted the dominating effect in the case of these samples, or at least contributed materially to the effect.

The indication that no outstanding advantage resulted from the reduced sulphur and phosphorus contents of samples S-5 and S-6, previously noted in the analysis of the results presented in Table 5, was confirmed.

It was noted during welding the test plates that, in cases involving the use of rutiles of sulphur contents of 0.33% and above, the performance of the electrodes was adversely affected. The molten pool was very turbulent, and the slag failed to furnish a uniform protective coating over the solidifying weld metal. At 0.20% and below, performance was satisfactory.

Information on the quantitative effects of sulphur in welding electrode coatings, independent of other possible effects inherent in the Arkansas rutiles, was sought by preparing lots of experimental electrodes, using in their coatings commercial-grade rutile to which pyrite was added in varying amounts as an impurity. The quantity added was calculated to correspond to the sulphur content of samples S-2, S-3, S-4 and S-5 of Arkansas rutile, and Formula B was used in the coating preparations. These lots were designed to furnish information on the basic effect of the sulphur against which the corresponding results from Arkansas rutile, as shown in Table 6, could be judged.

The results from these electrodes are tabulated in Table 7, together with A.S.T.M. minimum requirements and comparable data from experimental electrodes not containing sulphur contamination.

Table 5—Comparison of Physical Properties of Weld Metal

			Experimental electrodes, coating Formula A							
	A.W.S.-A.S.T.M. minimum requirements		*Containing commercial-type rutile (from Table 2)*		*Containing S-4 Arkansas rutile*		*Containing S-5 Arkansas rutile*		*Containing S-6 Arkansas rutile*	
Property	*NSR*	*SR*	*NSR*	*SR*	*NSR*	*SR*	*NSR*	*SR*	*NSR*	*SR*
Yield point, psi.	52,000	47,000	65,500	58,150	66,700	62,400	69,200	64,700	67,900	66,900
Tensile strength, psi.	62,000	60,000	76,500	70,100	78,200	74,450	81,200	75,900	76,900	74,100
Elongation, per cent in 2-in.-gage length	17	22	19.6	25.2	17.7	23.0	19.7	20.0	16.8	21.3

Table 6—Comparison of Physical Properties of Weld Metal

			Experimental electrodes, coating Formula B											
	A.W.S.-A.S.T.M. minimum requirements		*Containing commercial-type rutile (from Table 2)*		*Containing S-2 Arkansas rutile*		*Containing S-3 Arkansas rutile*		*Containing S-4 Arkansas rutile*		*Containing S-5 Arkansas rutile*		*Containing S-6 Arkansas rutile*	
Property	*NSR*	*SR*	*NSR*	*SR*	*NSR*	*SR*	*NSR*	*SR*	*NSR*	*SR*	*NSR*	*SR*	*NSR*	*SR*
Yield point, psi.	52,000	47,000	67,300	64,700	70,700	67,300	70,200	67,850	73,200	70,900	73,000	70,850	73,400	72,150
Tensile strength, psi.	62,000	60,000	79,700	76,600	77,800	75,800	82,350	82,100	86,100	80,100	86,700	82,600	84,800	82,500
Elongation, per cent in 2-in.-gage length	17	22	17.3	23.0	9.4	17.2	12.5	13.65	15.1	20.9	14.8	18.9	12.9	18.3

Table 7—Comparison of Physical Properties of Weld Metal

			Experimental electrodes—coating Formula B									
	A.W.S.-A.S.T.M. minimum requirements		*Containing commercial-type rutile, (from Table 2)*		*Containing commercial-type rutile, 1.06% S added*		*Containing commercial-type rutile, 0.33% S added*		*Containing commercial-type rutile, 0.20% S added*		*Containing commercial-type rutile, 0.09% S added*	
Property	*NSR*	*SR*	*NSR*	*SR*	*NSR*	*SR*	*NSR*	*SR*	*NSR*	*SR*	*NSR*	*SR*
Yield point, psi.	52,000	47,000	67,300	64,700	55,100	50,000	69,300	65,200	68,650	67,350	67,900	68,500
Tensile strength, psi.	62,000	60,000	79,700	76,600	55,600	50,000	80,600	76,150	80,100	77,050	79,700	78,350
Elongation, per cent in 2-in.-gage length	17	22	17.3	23.0	3.4	3.4	16.2	19.2	18.7	23.5	17.7	25.0

The results disclose an embrittling effect for the sulphur additions, conclusively in the cases of 0.33- and 1.06-% additions, and tentatively in the cases of the 0.20- and 0.09-% additions. Performance and test results in this and former trials involving rutiles containing 1.06% sulphur were so erratic as to render quantitative comparisons unreliable.

At 0.20% sulphur and below, the adverse effects were so slight as to be inconclusive. At the higher figures, performance of the electrodes during welding of the test plates was unsatisfactory, corresponding closely to that previously observed with the high sulphur Arkansas rutiles.

Comparison between commercial and Arkansas rutiles of equal sulphur contents, as they appear in Tables 6 and 7, respectively, indicates that sulphur did not have as great an adverse effect as an added pyrite impurity in commercial rutile as an equivalent natural sulphur content in Arkansas rutile. The uncomplicated presence of a pyrite impurity was therefore insufficient grounds for satisfactorily explaining the behavior of the Arkansas rutile samples. The complexity of occurrence of the sulphides in the Arkansas rutile opens a wide area for investigation as to the effect of small quantities of these and other constituents on electrode performance.

Analytical studies were made on the distribution of the sulphur and phosphorus impurities in rutiles, the coatings in which these rutiles appeared as a constituent and weld metal deposited from electrodes so coated. A concentration of sulphur in the weld metal above the tolerable limits for mild steel was detected in the cases of coatings made from rutiles containing 1.06% sulphur, and this was true both for Arkansas rutile and for commercial rutile to which this quantity of sulphur was added as an impurity. When rutiles below this sulphur content were used, no relationship was established between the quantities of sulphur present in the electrode coating and in the resultant weld metal.

All the weld samples showed paler sulphur prints than the adjacent plate material or the core wire, even though the sulphur content was in some cases actually higher. This effect is attributed to the higher degree of dispersion or finer state of division of the sulphide in the weld metal. Sloman, Rooney and Schofield reported the same behavior in an investigation of the constitution of weld deposits.[3]

No significant concentration of phosphorus in the weld metal was detected in tests of electrodes in which the coating contained up to 0.29% of this element in the rutile component. Hence the observed variation in properties of the experimental electrodes cannot be directly associated with this impurity. One of the leading producers of welding electrodes stated in a private communication that 0.5% phosphorus in the rutile has been permissible without deleterious effects on the deposited metal. Reeve[4] has reported that the ductility of mild-steel weldments is not impaired by the presence of 0.070% phosphorus.

Photographs of representative fractures of the all-weld-metal tensile specimens, both as-welded and stress-relieved, are reproduced in Figs. 1 to 5, inclusive. The stress-relieved specimens are readily identified by the comparatively greater reduction in area and the absence of "fish eyes." Although some questions remain unanswered regarding the formation of this characteristic imperfection, which has been associated with hydrogen and moisture contents,[5] it is evident that all specimens in this investigation, including the commercial rods, exhibited substantially the same size and number of fish eyes. Extensive metallographic study of the microstructure of the various specimens in this investigation has revealed that the welds have substantially the same grain size and cleanliness ratings. Only a few specimens were found that contained nitride structures, and these were small areas of a rather localized nature. Thus far, no correlation has been found between the microstructural characteristics of the metal, fractures and the mechanical properties of the various coated electrodes.

Welding engineers have repeatedly pointed out that the E-6012 type electrode does not excel in ductility and in many instances barely passes the minimum specifications,[6,7] although they have given quite satisfactory service. Under the conditions of this investigation, the mechanical properties of weld metal from Arkansas rutile rods are inferior to the commercial rutile rods in that the strength values are high and the ductility is low. In several instances, individual welds produced have enough ductility to meet the A.W.S.-A.S.T.M. requirement of 17%, but the values from weld to weld vary and the observed properties place the material in a doubtful category.

An independent test of the Arkansas rutile in electrode coatings was made through the cooperative efforts of Dr. David F. Helm, senior fellow, Mellon Institute of Industrial Research, Pittsburgh, Pa. Dr. Helm arranged for the fabrication of "typical commercial" electrodes containing both Arkansas rutile and a control electrode with commercial rutile which were subsequently used in the standard weld-metal test. The results of these tests confirmed the technique used in this investigation and substantiated the findings regarding the weld-strength properties as influenced by the character of the rutile in the coating formula. The performance and mechanical properties for both the commercial rutile and Arkansas-rutile-coated electrodes were found to be approximately the same as given in this report.

An explanation of the experimental re-

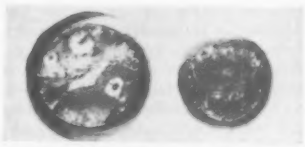

Fig. 1 As-welded and stress-relieved fracture sections of weld-metal tensile specimens made with Type E-6012 commercial electrode. × 2

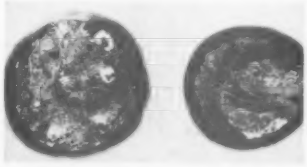

Fig. 2 As-welded and stress-relieved fracture sections of weld-metal tensile specimens made with experimental electrode containing commercial rutile in Formula A. × 2

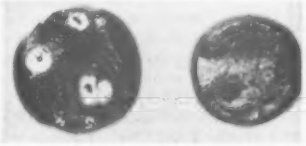

Fig. 3 As-welded and stress-relieved fracture sections of weld-metal tensile specimens made with experimental electrode containing commercial rutile in Formula B. × 2

Fig. 4 As-welded and stress-relieved fracture sections of weld-metal tensile specimens made with experimental electrode containing Arkansas rutile S-4 in Formula A. × 2

Fig. 5 As-welded and stress-relieved fracture sections of weld-metal tensile specimens made with experimental electrode containing Arkansas rutile S-4 in Formula B. × 2

sults requires further investigation and identification of those factors which have a direct bearing on the suitability of the material as a component in electrode coatings. Additional information regarding slag characteristics such as softening and fusion temperatures, viscosity, etc., the influence of the reducibility of the various forms of rutile and a quantitative evaluation of their arc-stabilizing power or possible breakdown in structure in the range of the arc temperature will assist materially in analysis of the general problem.

Isolation of the inherent factor may also permit the development of coating mixtures which would compensate the inhibiting characteristics of Arkansas rutile and make this mineral deposit acceptable for commercial use in welding electrodes.

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A.S.T.M. Meetings

Sessions on Plasticity and Creep of Metals; Fatigue of Metals; Application of Statistics; Dynamic Stress Determinations; Symposium on Cast iron at A.S.T.M. Pacific Area Meeting

DURING the First Pacific Area National Meeting of the American Society for Testing Materials in San Francisco, Calif., October 10-14th inclusive, numerous technical papers will be presented of interest to those in the metals field. Sessions on Monday, October 10th, cover Plasticity and Creep of Metals and Fatigue of Metals. There are sessions on Tuesday dealing with Dynamic Stress Determinations and Applications of Statistics that will interest the metals fraternity, and on Thursday, a Symposium on Cast Iron is scheduled, sponsored by A.S.T.M. Committee A-3 on Cast Iron.

PLASTICITY AND CREEP OF METALS

The four papers in this session at 2 P.M., October 10th, are by leading authorities in their fields and cover the following: "The Experimental Exploration of Plastic Flow in Sheet Metals"—L. R. Jackson, Battelle Memorial Institute, Columbus, Ohio, and W. T. Lankford, Carnegie-Illinois Steel Corp., Pittsburgh, Pa.; "Application of Forming Criteria to Production Problems"—W. Schroeder, Lockheed Aircraft Corp., Burbank, Calif.; "Use of Creep Data in Design"—Howard C. Cross and L. R. Jackson, Battelle Memorial Institute, Columbus, Ohio; "Super Creep-Resistant Alloys"—J. W. Freeman, D. N. Frey and E. E. Reynolds, University of Michigan, Ann Arbor, Mich.

FATIGUE OF METALS

On Monday evening, October 10th, four papers on the subject of Fatigue will be given as follows: "Introduction to Fatigue Session"—"A Broad Look at the Fatigue of Materials Field"—R. E. Peterson, Westinghouse Electric Corp., East Pittsburgh, Pa.; "Fatigue Strength of Steel Through the Range from 0.5 to 30,000 Cycles of Stress"—M. H. Weisman, North American Aviation, Inc., Inglewood, Calif.; "Fatigue Notch Sensitivities of Some Aircraft Materials"—H. Grover, Battelle Memorial Institute, Columbus, Ohio; "Fatigue Strength of Aircraft Materials and Fastenings"—Thomas Piper, Northrop Aircraft, Inc., Hawthorne, Calif.

DYNAMIC STRESS DETERMINATIONS

Growing interest in dynamic testing and stress analysis is recognized through a separate session the morning of October 11th, with the following four papers: "A Survey of Pick-ups for Dynamic Physical Measurements"—Gifford White, Statham Laboratories, Beverly Hills, Calif.; "Selection of Recording Equipment for Dynamic Testing"—K. D. Swartzel, Cornell Aeronautical Laboratory, Inc., Buffalo, N. Y.; "Analysis and Interpretation of Dynamic Records"—H. C. Roberts, University of Illinois, Urbana, Ill.; "Some Examples of Dynamic Testing in the Field of Materials and Structures"—Douglas McHenry and H. E. Hosticka, U. S. Bureau of Reclamation, Denver, Colo.

APPLICATION OF STATISTICS

The Society and its members are much concerned with quality control of materials and the application of statistics, and a separate session on Tuesday afternoon, October 11th is devoted to applying statistics, with three papers: "Some Economic Aspects of Vendor-Purchaser Relationships When Specifications Are Statistically Unenforceable"—E. L. Grant, Stanford University, Stanford University, Calif.; "Precision and Accuracy of Test Methods"—Grant Wernimont, Eastman Kodak Co., Rochester, N. Y., and "Use of Statistics to Determine Accuracy of Tentative Test Methods"—W. J. Youden and J. M. Cameron, National Bureau of Standards, Washington, D. C.

SYMPOSIUM ON CAST IRON

A wealth of information on the properties and testing of cast iron, the significance of specifications for this material and information on extensive uses of castings will be covered in this Symposium the afternoon of October 13th. Four papers will form the basis of the Symposium, as follows: "Mechanical Testing and Properties of Gray Cast Iron"—C. K. Donoho, American Cast Iron Pipe Co., Birmingham, Ala.; "Development, Significance and Uses of Specifications for Cast Iron"—H. Bornstein, Deere and Co., Moline, Ill.; "Automotive Cast Irons, Including Brake Drums"—R. G. McElwee, Vanadium Corporation of America, Detroit, Mich.; "Applications and Uses of Gray Iron Castings, Including Significance of Various Properties of Gray Cast Iron"—C. O. Burgess, Gray Iron Founders' Society, Cleveland, Ohio. In one or more of the papers, the use of cast iron at elevated temperatures will be reviewed.

All engineers, technical people and others concerned with materials are cordially invited to attend this A.S.T.M. National Meeting. Copy of the complete program can be obtained by writing to A.S.T.M. Headquarters, 1916 Race St., Philadelphia 3, Pa. It is not expected that the papers will be preprinted, but duplicated copies are to be made available to those registering at the Meeting. All sessions are at the Fairmont Hotel.

Electrical Problems in Argon-Shielded Arc Welding Thick Aluminum

Some of the electrical problems encountered in argon-shielded arc welding thick aluminum plate are briefly described and solutions indicated

by R. D. Williams, P. L. Mirolo and C. B. Voldrich

INTRODUCTION

IMMEDIATELY after World War II, the Linde-Frankel process for the production of cheap oxygen opened a whole new field of industrial uses for oxygen. Of particular interest was its use in converting natural gas to gasoline and in raising the efficiency of blast furnaces for the production of steel. The process required for many of its production components, material which would remain strong and tough at temperatures as low as −320° F. Aluminum was one of the materials selected for this application, because at such temperatures the nonheat-treatable grades of aluminum (2S and 3S) would double or triple in tensile strength, with no appreciable decrease in ductility. In order to meet the strength requirements for some parts of the oxygen plants, it was necessary to weld thicknesses of aluminum plate, 2 in. or more—a procedure never before considered on a production basis.

At about the same time, military requirements had led to a need for developing welding procedures for joining thick aluminum-alloy plate of the heat-treatable types (61S, 24S, 75S, etc.).

For the past three years Battelle has been investigating the welding of thick aluminum plate. Much of the material in the paper is related to problems encountered during research projects conducted for the Stacey Brothers Gas Construction Company of Cincinnati and the Army Ordnance Dept. The authors are grateful to these two organizations for permission to use this material.

Although not necessarily restricted to thick-section welding, the problems discussed have been of particular significance in this application. Five of them, particularly interesting from an electrical standpoint, will be discussed in this paper. These are (1) the magnitude of the welding current; (2) the effect of rectification of the welding current; (3) the effect of high-frequency stabilization; (4) the effect of open-circuit voltage; and (5) the control of wire feed for mechanized welding.

R. D. Williams, P. L. Mirolo and C. B. Voldrich are with the Battelle Memorial Institute, Columbus, Ohio.

This paper was presented at A.I.E.E. Conference on Electric Welding, Detroit, Mich., Dec. 6, 1948.

WELDING EQUIPMENT AND MATERIALS

At Battelle, most of the argon-arc welding of thick aluminum sections has been done with two standard 500-amp. high-capacity alternating-current welding transformers connected in parallel to give welding currents up to 1000 amp. These transformers had open-circuit voltages of about 80 v. A 1000-amp. spark-gap oscillator and usually two or more 6-v. storage batteries for balancing the welding current were connected in series in the welding circuit.

Tests were also made with an 800-amp. high-reactance transformer especially designed for inert-gas-shielded arc welding. This transformer had built-in remote current control (crater eliminator), condensers for balancing the welding current, a high-frequency pilot circuit (which acted instantaneously to establish the arc) and a selection of open-circuit voltages of either 100 or 150 v.

Larger sized welding torches than those commercially available (at least at the start of the work) were used. Their design was generally similar to that of the smaller torches, except that water-cooled copper nozzles for introducing the argon around the electrodes were used instead of the ceramic nozzles of the smaller torches, because of the more intense welding heat. The larger torches could hold electrodes $^1/_4$ to $^1/_2$ in. in diameter. These electrodes were either solid tungsten or tungsten tipped, with a water-cooled copper-tube extension.

The filler rods used were $^1/_8$- to $^5/_{16}$-in.-diameter rounds of 2S, 3S, 43S, 61S, 24S, 75S and 71S compositions.

The base plate ranged from $^1/_2$ to $2^1/_2$ in. in thickness and included the nonheat-treatable types, 2S and 3S, and the heat-treatable high-strength alloys, 61S, 24S and 75S.

MAGNITUDE OF WELDING CURRENT

Most of the welding was done with the argon-shielded tungsten-arc process. This process was selected after a study of all commercially available processes for welding aluminum, because it proved the most satisfactory for research and for many of the production applications toward which the research was directed. The reasons for the selection were fourfold: (1) weld deposition was smooth, leading to optimum weld quality; (2) weld deposition could be readily observed, because there was no covering of flux, nor fuming during welding; (3) there was no danger of flux entrapment in the weld metal, nor any need for flux removal after welding; and (4) welds could be deposited in the vertical and overhead positions. The chief disadvantages of argon-arc welding are the high cost of argon (about 10¢ per cubic foot), and the relatively slow deposition rates obtainable.

For the welding of thick aluminum plate, high currents are desirable in order to permit the use of simple joint designs and to allow the joints to be made at high speeds. In the first experiment, tests were made with both alternting current and direct current. The results confirmed published information on thin-section welding, which indicated that for the currents required, only alternating-current welding could be used.

It was found that the usable direct current was limited roughly to 150 amp. Above this, the tungsten electrodes overheated and melted, if reversed polarity (electrode positive) were used, while with straight polarity (electrode negative) sound welds could not be produced. When welding with alternating current, the weld pool and immediately adjacent plate were cleaned during the half cycle when the electrode was positive, and during the subsequent half cycle the greater proportion of the welding heat was concentrated at the plate. This permitted the use of much higher currents.

In order to carry high currents, relatively large-diameter tungsten electrodes were used. They ranged from $^1/_4$ to $^1/_2$ in. in diameter in the Battelle investigation. It was found that for manual welding the maximum practical electrode diameter was $^5/_{16}$ in.—for any larger diameter, the torch would have been too bulky for the welders to handle. In mechanized welding, this size limitation did not exist, and while the largest diameter thus far used has been $^1/_2$ in., larger diameters are being considered—in fact a $^3/_4$-in.-diameter electrode has already been constructed.

Unfortunately, the welding of thick plate is not merely a matter of applying higher currents through thicker electrodes, because with the higher currents other interdependent factors, not too important in thin-section welding, become predominant. These include welding speed and arc length. It has been found that for a given welding speed, a higher current can be used if the arc length is increased; and that for a given arc length a higher current can be used, if the welding speed is increased. A typical example of this relationship was observed in laying a weld bead with a $^1/_2$-in.-diameter electrode on a 400° F. preheated 1-in. aluminum plate, at a speed of 8 in. per minute. With a $^5/_{16}$-in. arc length, the maximum current that could be used was 725 amp. With any higher current, the weld pool boiled violently and the electrode melted; but if the arc length was increased to $^1/_2$ in., the current could be raised to about 750 amp. before the same thing happened. Furthermore, if the speed were then increased to 24 in. per minute, the current could be raised to about 950 amp. before the weld pool began to boil, and even then the electrode did not melt, although spatter from the pool tended to make the arc erratic.

It is believed that the reduction in the tendency for the electrode to melt when the arc length or welding speed was increased, was because both of these adjustments tended to reduce the amount of heat reflected back to the electrode from the weld pool. Unfortunately, the initial weld passes in joints in thick plate require welding speeds that are fairly slow, in order to obtain satisfactory penetration. This limits the maximum current that can be used. It therefore becomes necessary to select for each plate thickness and weld pass a satisfactory combination of welding current, electrode diameter, welding speed, and arc length. When the interrelation of these four variables is understood, this is not too difficult.

EFFECT OF RECTIFICATION

During the early tests with high welding currents, the arc was less stable than expected, and oscillographic measurements indicated that a direct-current component of as much as a third of the recorded alternating current was present, e.g., a direct-current component of about 150 amp. existed with a recorded alternating current of about 450 amp. It had been known that an unbalanced current would exist when an arc was produced between electrodes of different materials (i.e., tungsten and aluminum); but, it had not been anticipated that the degree of unbalance would be so great, nor that it would seriously affect the arc stability.

Manual welding was used in all the earlier tests and is still being used for much of the experimental work. As the welders became experienced in welding, they were able to adjust their technique to compensate for the effects of unbalanced current on arc stability. Although many of the later tests were made with the current balanced, tests of welds deposited by both types of current indicated that the partial rectification had no appreciable effect on the weld quality.

This was not true for mechanized welding, because with the current, speed, arc length and wire feed fixed, it was impossible to make instantaneous adjustments for arc instability caused by unbalanced current. Therefore, balanced current was always used.

Partial rectification can be balanced out in two different ways. Storage batteries, themselves connected in parallel, can be connected in series into the welding circuit so that they will cancel the direct-current component (it is a very fortunate coincidence that the voltage of the direct-current component is about 6 v., so

that ordinary automobile batteries can be used for this purpose); or condensers can be connected into the welding circuit, so that they will "block out" the direct-current component.

Another undesirable effect of unbalanced current was also encountered early in the investigation. Fuses in the primary side of the circuits were burning out at frequent intervals. As soon as the oscilloscopic measurements had revealed the degree of partial rectification, the cause of the overloading was apparent, i.e., the total power input, including both the alternating current (measured by ammeters of the current-transformer type) and the unmeasured direct current, was exceeding the fuse capacity. The danger of overloading the primary circuit can be eliminated by computing the root mean square value* of the current, which includes the direct-current component, but it can be done more simply by using direct-reading ammeters. In industry, this danger is frequently avoided by arbitrarily limiting the maximum welding current to 80% of the rated transformer capacity.

HIGH-FREQUENCY STABILIZATION

Failure of the arc to reignite after deionization during reversal of the alternating current is inherent in all types of alternating-current welding. In argon-arc welding of thick aluminum, it causes instability or total extinguishment of the arc. One method of preventing this is to use high-frequency stabilization, gene,ally supplied by a spark-gap oscillator connected into the welding circuit. With standard welding transformers having 80- to 100-v. open-circuit voltages, continuous high frequency is generally used. With the transformers especially designed for inert-gas-shielded tungsten-arc welding, having higher open-circuit voltages (100 to 150 v.), a pilot high frequency, which acts for a fraction of a second at the start of the weld, or whenever the arc is unintentionally extinguished, maintains a stable arc.

The relative merits of continuous vs. instantaneous high frequency will be discussed in detail in other papers presented during the conference. Most of the welding tests at Battelle have been made with standard transformers using continuous high-frequency stabilization but a few tests have been made with the other system for purposes of comparison. For manual welding, no significant differences were observed between the two systems either in arc stability, and consequent ease of weld deposition, or in the quality of the welds themselves. For mechanized welding, a longer stable arc could be held when the continuous high-frequency system was used. This is a definite advantage, because the longer arc allows some leeway in the mechanical feeding of the filler wire into the pool. The ability to maintain a longer arc also makes this system more adaptable to sudden changes in arc length brought about by changes in the surface level of the weld pool. This is important because in thick-plate welding these changes may amount to $^1/_8$ in. or even more.

One disadvantage of high-frequency stabilization is that there is a tendency for the arc to jump to the sides of grooved joints in thick plate instead of going to the weld pool. Another possible disadvantage is that it may interfere with radio reception, since most stabilizing circuits have frequencies lying within radio wave bands. Such interference would be negligible with the instantaneous pilot high-frequency system, but a recent ruling of the Federal Communications Commission has recognized the possibility of interference, at least from the continuous systems. No interference from several continuous high-frequency oscillators in the Battelle Welding Laboratory has been reported, and careful tests have failed to pick up any signal from them outside the building.

High Open-Circuit Voltage

High open-circuit voltages in the order of 150 volts are also known to be useful in minimizing arc instability produced by deionization during the reversal of alternating current. Welding tests were made with low (80 to 100 v.) and high (150 v.) open-circuit voltages using both the standard transformers, which could be connected in series to give the high open-circuit voltages, and the special transformers designed to permit selection of either high or low open-circuit voltages.

With the high currents used for welding thick plates, no difference in arc stability could be detected in the former system, which had continuous high-frequency stabilization, nor in the latter, which had the high-frequency pilot, regardless of the open-circuit voltages.

It was concluded therefore that from a laboratory standpoint there was no advantage in using high open-circuit voltages for thick-plate welding. It would nevertheless be expected that a high open-circuit voltage might be preferable with systems using instantaneous high-frequency stabilization, because this would in itself stabilize the arc, thus minimizing the need for the pilot high frequency after the weld had been started.

Wire Feed for Mechanized Welding

Mechanized argon-arc welding has frequently been referred to during this paper. There are several obvious advantages in the mechanized welding of thick plate, chief among them being the freedom to use higher currents, because the size of the torch is not limited to what a welder can handle; the ability to make long continuous seams; and increase in operator comfort, because of the elimination of torch and filler wire manipulation, and because of a reduction in exposure to the high preheat and welding temperatures encountered in the welding of thick plate.

Ideally, mechanized argon-arc welding would be a fully automatic, push-button type of operation, as is already essentially true for the submerged-melt welding

* Rms. = $\sqrt{AC^2 + DC}$ where $\overline{AC}$ = rms. alternating-current value, and DC = direct-current c

of steel. Unfortunately there is at least one major deterrent to the development of fully automatic argon-arc welding of thick plate—the need for controlling the speed of the filler-wire feeding mechanism.

The welding variable most frequently used for control circuits of the type needed is the arc voltage, which reflects directly any changes in arc length. This is readily applicable to the metal-arc welding of steel where the filler wire, i.e., electrode, is a part of the welding circuit and relatively small changes in arc length produce appreciable changes in arc voltage; e.g., a change of 0.1 in. in arc length may produce a change in arc voltage of 5–10 v.

For tungsten-arc welding in an argon atmosphere, even with the high currents used for welding thick plate, the changes in arc voltage induced by changes in arc length are much less—roughly 4 v. for a change of $^1/_4$ in. in arc length, at currents of 600–700 amp. Furthermore, the filler wire is independent of the welding circuit. Although commercial equipment has recently been developed for controlling the length of the tungsten arc through an electronic circuit which magnifies the changes in arc voltage, no suitably responsive wire-feed-speed control has yet been developed. Such a control would be more difficult to attain because of the much greater speeds involved. For example, the maximum variation in arc length with no control is only of the order of $^1/_4$ in., and the electrode-feed speeds necessary to maintain a fairly constant arc length would not be great. Onthe other hand, filler-wire feed speeds required for welding thick plate with $^1/_8$-in.-diameter wire are frequently 50 in. per minute or more, and with smaller diameter wire are even higher.

It has been reported in private communications that with thinner plates, a preset constant-speed wire feed is working very satisfactorily, in conjuction with the equipment for controlling arc length, already mentioned. This method is to be investigated, because other techniques such as underfeeding and overfeeding of the filler wire, and varying the diameter of the filler wire, have proved unsatisfactory.

The present practice is to control the wire feed speed manually, and this, of course, requires the presence of a skilled operator at all times. Even so, this method is not entirely consistent, as the instantaneous manual control of the various interrelated factors of welding speed, arc length and filler-wire feed speed is very difficult.

FUTURE OUTLOOK FOR WELDING THICK ALUMINUM PLATE

Certain of the problems presently existing in the argon-shielded tungsten-arc welding of thick sections of aluminum can doubtless be overcome. This is particularly true of those problems associated with equipment, because considerable effort is being directed toward the improvement of available equipment. This will be brought out in other papers presented during the conference.

Some of the problems related to the tungsten-arc welding process have been completely eliminated by the Aircomatic process, developed at the Air Reduction Sales Company Research Laboratories and at Battelle, which was introduced at the 1948 Metal Congress. This process uses an argon-shielded, consumable coiled electrode, and the welding current required can be supplied by standard direct-current welding generators. Use of direct current automatically eliminates the problem of partial rectification and the need for any type of high-frequency stabilization. Furthermore, with the filler-wire (electrode) forming part of the welding circuit, lower welding currents are used than for comparable welds made with the tungsten-arc process, resulting in greater deposition efficiency.

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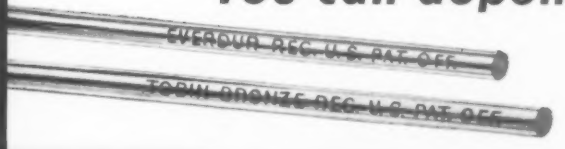

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